The TREND IN ENGINEERING

at the University of Washington

In this issue:

- Vibration Studies at Ross Dam
- Diffusion in Agar Gels
- Dielectric Heating
- Electroforming Iron
- Tests for Shear Resistance of Soils
- Engineering Geology of West Seattle Area
- Ceramic Tests of Pacific Northwest Clays
- Corrosion Studies on 24ST Aluminum

July, 1949

VOL. 1, No. 3

WROTE the governor of Mauretania to the governor of Numidia under date of 152 A.D: "Kindly order the hydraulic engineer of the III legion, Nonius Datus, to finish the work (on the tunnel) which he has apparently forgotten."

Report of Engineer Datus: "After leaving my quarters I met with brigands on my way, who robbed me of even my clothes, and wounded me severely. I succeeded....in reaching Saldae where I was met by the governor, who, after allowing me some rest, took me to the tunnel. There I found everybody sad and despondent; they had given up all hopes that the two opposite sections of the tunnel would meet, because each section had already been excavated beyond the middle of the mountain, and the junction had not yet been effected. As always happens in these cases, the fault was attributed to the engineer, as though he had not taken all the precautions to insure the success of the work. What could I have done better? I began by surveying and taking the levels of the mountain; I marked most carefully the axis of the tunnel across the ridge; I drew plans and sections of the whole work which I handed over to....the governor of Mauretania; and to take extra precaution, I summoned the contractor and his workmen and began the excavation in their presence, with the help of two gangs of experienced veterans....What more could I have done? Well, during the four years I was absent....expecting every day to hear the good tidings of the arrival of the water at Saldae, the contractor and his assistant had committed blunder upon blunder; in each section of the tunnel they had diverged from the straight line, each toward his right, and had I waited a little longer before coming, Saldae would have possessed two tunnels instead of one." — Transcribed from Lanciani, *Ancient Rome*, page 61.

(*Ed. Note*: Datus finally connected the two parts of the tunnel by a transverse excavation.)

THE Engineering Experiment Station of the University of Washington was established in December, 1917, to co-ordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

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1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

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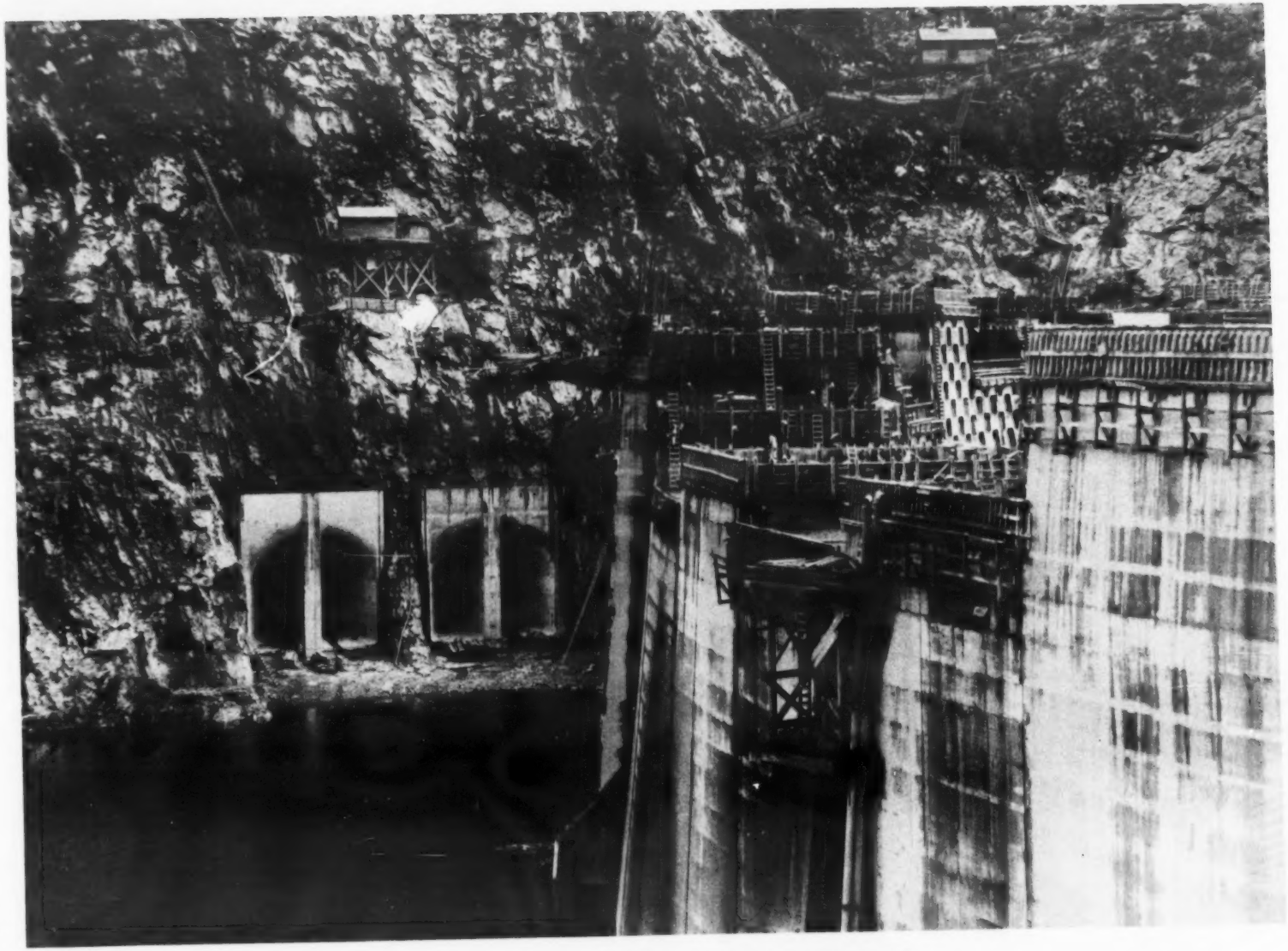
COVER

View from skip directly above Ross Dam, looking down on the first step. Photograph by Howard A. Coombs.



Left Bank of Ross Dam Showing Intake of Power Tunnels

VIBRATION STUDIES AT ROSS DAM

Howard A. Coombs

Professor of Geology

Introduction

The study of vibrations produced by blasting is an unusual procedure in the construction of a dam. The following pages present the reasons for the study, how the data were gathered, and an interpretation of the results with special reference to possible damage to the dam by the blasts. This problem was of particular interest to the writer who served as Consulting Geologist for the City of Seattle, Department of Lighting, and was in charge of the seismograph station at the University of Washington for many years. Ross Dam is unusual in that it has been subjected both to blasting vibrations and to the strong vibrations set up by the severe earthquake of last April 13. The dam has successfully resisted both types.

Ross Dam

Ross Dam is situated in the northern Cascades of Washington, approximately 20 miles south of the Canadian border. The City of Seattle, Department of Lighting, has constructed a series of dams along the Skagit River for hydro-electric purposes, and Ross Dam is the northernmost and highest dam in this series.

The dam is a concrete arch structure 208.5 feet thick at the base and 290 feet high from the lowest bed rock to the top of the first step. The distance between abutments along the crest is 775 feet and the crest thickness is 66 feet. The first step was completed in 1940.

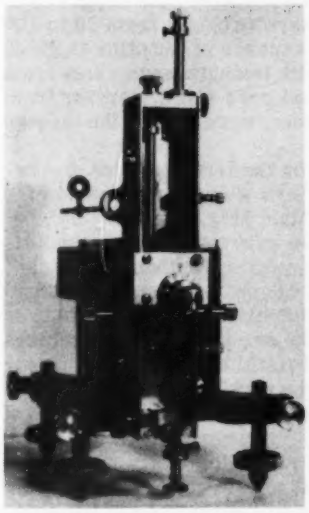


Fig. 1. U.S. Coast and Geodetic Survey Vibration Meter

During the war, the City of Seattle was asked by the War Production Board to raise Ross Dam in order to provide more reservoir storage and hence more power from existing facilities for Seattle. This work included the addition of 185 feet to the height of the dam and the installation of valves, gates and spillways for the regulation of water required for the lower powerhouses.

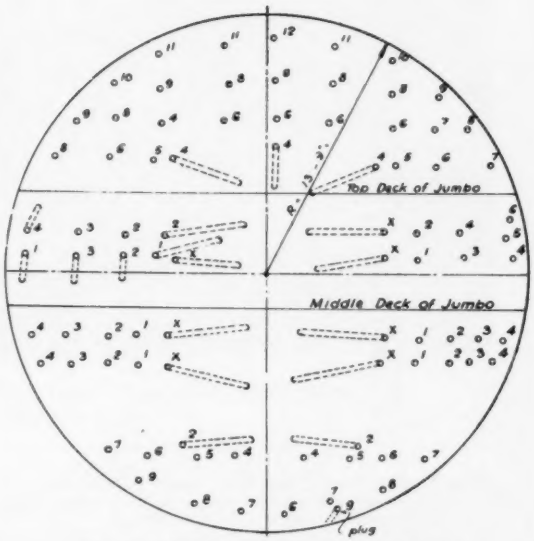


Fig. 2. Blasting Diagram for Tunnel
(X's show instantaneous blasts; the remaining holes are delayed in order from 1 to 12.)

Reasons for Vibration Study

The first and second steps of Ross Dam were built for the purpose of storing water. Ultimately, however, when the dam is raised to its full height, the great head of water will be used for hydro-electric purposes. As part of this plan, two 27-1/2-foot power tunnels were to be driven around the left bank of the dam at an elevation of approximately 1425 feet. This would be about 60 feet above the top of the first step. The Board of Consulting Engineers thought it advisable to drive the power tunnels, or at least that portion of the tunnels near the dam, before the second step was emplaced because of the following reasons:

1. If the 27-1/2-foot power tunnels were driven after the second step was in place, the nearest tunnel would be less than 150 feet from the left edge of the dam. The setting off of 800 pounds of powder so close to newly poured concrete might damage the dam.
2. If the second step was in place and water backed up behind the dam, the dam would have to be unloaded before the blasting was started. At any rate, it would be necessary to draw the water down below the intake level of the power tunnels in order to drive the tunnels. In either case,

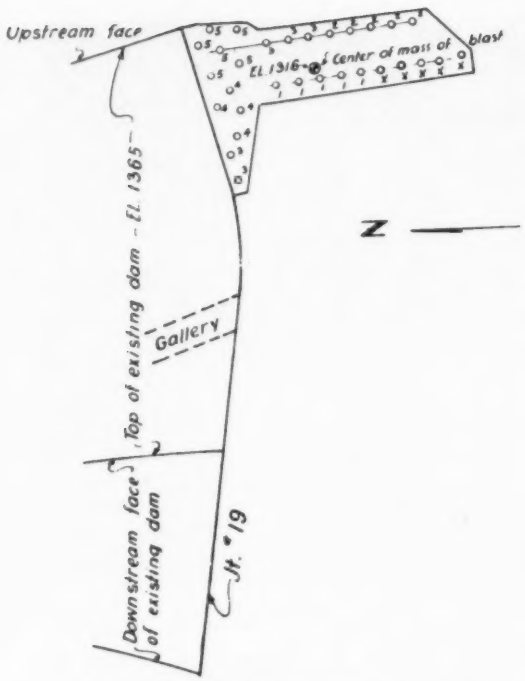


Fig. 3. Blasting Diagram, Left Abutment
(The seismometers were located in the gallery a few feet above and to the west of the blast.)

the drawing down of this great volume of water would be a severe economic loss to City Light.

3. If the second step was emplaced and grouted before the power tunnels were driven, blasting adjacent to the dam might possible damage the foundation grouting.

The engineers of the Federal Works Agency were in some doubt as to the possibility of damage by blasting so close to the dam. They contended that the tunnels could be driven later at a considerable saving in cost. In an attempt to obtain at least some data of a quantitative nature, the writer suggested the U.S. Coast and Geodetic Survey be asked to measure the intensity of the vibrations caused by blasting.

This work was done by Mr. Frank Neumann, Chief of the Section of Seismology, Mr. F. P. Ulrich, Chief Seismological Field Survey, and Mr. T. H. Pearce, Scientific Aid, all of the U.S. Coast and Geodetic Survey.

Instruments

It was realized by the U.S. Coast and Geodetic Survey that their instruments might not be satisfactory for recording the high-frequency waves expected in this new type of study, so every effort was made to test various instruments under actual field conditions. During the tests, four different types of instruments were used. They are as follows:

1. Neumann - Labarre vibration meters
   a. (Old type) T_0 - .85 sec., magnification=10,000
      Damping 8 to 10
   b. (New type) T_0 - .85 sec. to 3.0 sec., magnification=4000 to 8000
      Damping 8 to 10
2. 12-inch accelerometers
   T_0 - 0.10 sec., magnification=88
   Damping 8
3. Pin seismograph
   Six cylindrical rods 1.4 inches in diameter and lengths of 5, 6, 7, 8, 10, and 12 inches
4. Coast Survey vibration meters
   T_0 - 2.3 sec., magnification low
   Damping 8
   T_0 - 1.2 sec., magnification=1200
   Damping 8

The magnifications are for frequencies from approximately 2 to 10 cycles per second.

The Neumann-Labarre vibration meters had parasitic vibrations set up in them from the nylon filaments and other parts of the instruments and the results were not satisfactory.

In the 12-inch accelerometers, the helical springs set up parasitic vibrations at the high frequencies and the records are of doubtful value.

The pin seismograph was used a number of times, but the high-frequency vibrations from the blasting did not tip over any of the pins at any time.

The most satisfactory instrument was the Coast Survey vibration meter which is essentially an inertia seismometer of the Wood-Anderson type. Only the two horizontal components of the vibrations were measured. This instrument is shown in Fig. 1.

Field Observations

Vibrations were set up by charges of 60 per cent dynamite varying in the tunnel blasts from 700 to 800 pounds and in the keyway blasts from 68 to 150 pounds. In Fig. 2 the sequence of shooting is given for the tunnel blasts with instantaneous shots from holes 1 to 12. The initial core shots, varying from 65 to 110 pounds of powder, were always the strongest of the series.

In the keyway shots on the left abutment, the recording vibration meters were very close to the center of mass of the blast (Fig. 3).

As the vibrations are generated, they pass outward in all directions through rock composed essentially of granite-gneiss, migmatites and mica schists transected by scattered aplitic and basic dikes. For the most part, the rocks are jointed into a rectangular pattern characteristic of granites, but near fault and shear zones, the rock is shattered into fine slivers and slabs and contains occasional seams of gouge.

During the tests, the recording instruments were located at 12 different observation points. Some observation points were on the rock of the left abutment, some in the opposite tunnel from which the

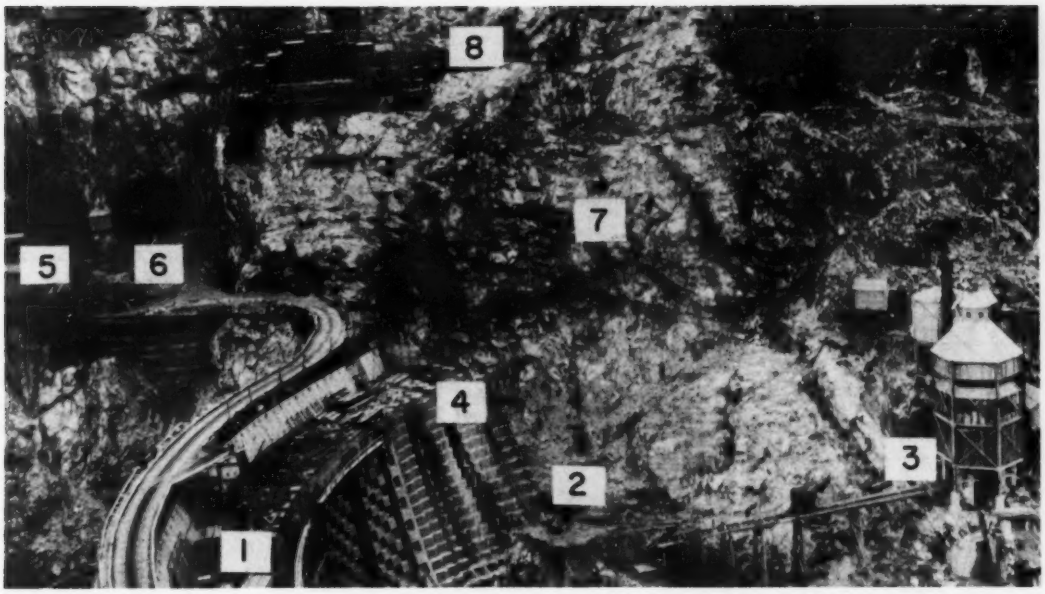


Fig. 4. Left Abutment, Spillway Area and Power Tunnel Intake Showing Location of Observation Points

1. Topcenter of Dam
2. Left Keyway
3. Mixing Plant
4. Left Gallery
5. Power Tunnel
6. Power Tunnel
7. Test Adit
8. Lumber Piles

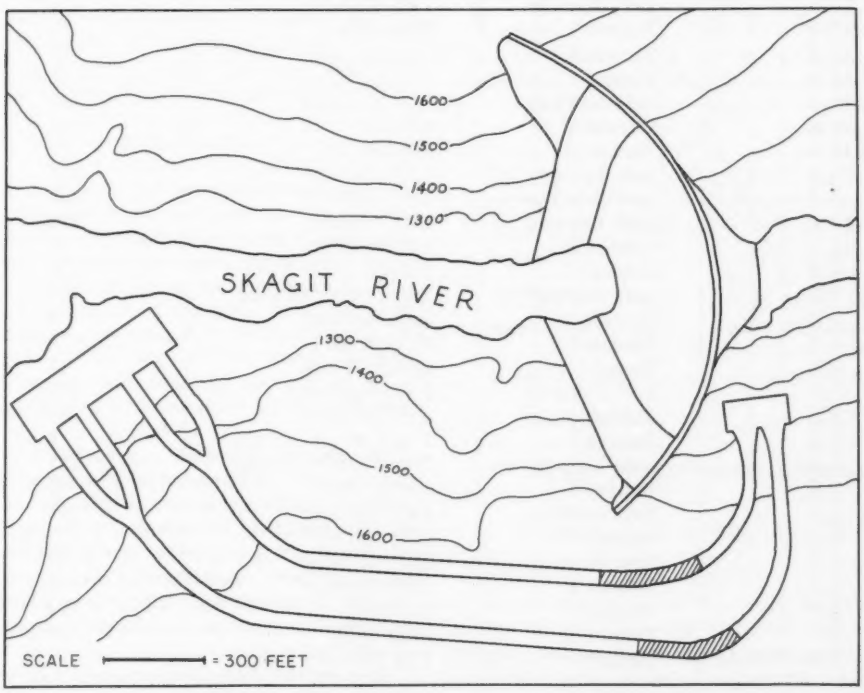


Fig. 5. Sketch of Ross Dam and Power Tunnels

(The tunnels are completed for only a short distance past shaded areas which indicate zones where blasts were set off and vibrations recorded.)

TABLE I

INSTRUMENTAL RESULTS FOR INITIAL SHOTS - ROSS DAM, 2ND STEP

Arranged in order of decreasing acceleration

Acceleration % of gravity	Shot point	Observation point	Energy factor
169.5(?)	Tunnel 1	Tunnel 2	4400?
76	Tunnel 1	Tunnel 2	1930
22.3	Tunnel 1	Tunnel 2	380
20.0	Tunnel 1	Tunnel 2	345
18.1	Left Keyway	Left Gallery	780
18.1	Tunnel 2	Left Keyway	134
16.2?	Left Keyway	Left Gallery	820
16.1	Tunnel 2	Tunnel 1	185
15.9	Tunnel 2	Tunnel 1	128
15.6	Tunnel 1	Tunnel 2	246
15.1	Tunnel 1	Mixing Plant	71
13.9	Tunnel 2	Tunnel 1	162
12.9	Left Keyway	Left Gallery	460
12.8	Tunnel 2	McGee Hill	132
12.6	Tunnel 1	Test Adit	122
12.5	Left Keyway	Left Gallery	320
12.4	Tunnel 1	Test Adit	111
12.2	Tunnel 2	Left Keyway	47
12.0	Tunnel 1	Level 1515	73.3
11.8	Left Keyway	Left Gallery	240
10.8	Tunnel 1	Mixing Plant	67.3
10.6	Tunnel 2	McGee Hill	56
10.4	Left Keyway	Left Gallery	450
10.4	Left Keyway	Left Gallery	340
10.4	Left Keyway	Left Gallery	300
10.1	Tunnel 2	McGee Hill	75
10.0	Tunnel 2	Tunnel 1	158
9.3	Left Keyway	Top Center of Dam	457
9.2	Tunnel 2	Left Keyway	35
9.1	Tunnel 2	McGee Hill	70
9.1	Tunnel 1	Mixing Plant	44
8.9	Left Keyway	Left Gallery	180
7.5	Tunnel 2	Left Gallery	43
7.5	Tunnel 1	Top Center of Dam	1.82
7.0	Left Keyway	Top Center of Dam	123
7.0	Tunnel 1	Level 1515	60.5
6.3	Left Keyway	Left Gallery	116
6.1	Tunnel 2	Left Gallery	27.4
6.0	Left Keyway	Left Gallery	99
5.6	Tunnel 2	Left Keyway	11.2
5.1	Tunnel 1	Tunnel 2	14
5.1	Tunnel 1	Test Adit	40.8
5.0	Tunnel 1	Top Center of Dam	16.9

blasts were set off, and others were on the dam itself. The photograph of the left abutment and power tunnel intake shows the location of a few of the observation points (Figs. 4 and 5).

Messrs. Neumann, Ulrich, and Pearce of the U.S. Coast and Geodetic Survey tabulated the results of their measurements in a report to the City of Seattle, Department of Lighting. Mr. Neumann calculated the acceleration in per cent of gravity and also gave for each recording, an "energy factor" defined as "the square of the maximum velocity which is equivalent to the displacement (single amplitude) in cm. times the acceleration in cm./sec.^{2}" Mr. Neumann further states, "It is of significance only as a measure of the *relative* energy of the recorded rock motions, since kinetic energy is a function of the square of the velocity of the motion."

Interpretation of Results

In going over the observations made by the U.S. Coast and Geodetic Survey, the writer has selected the results showing the greatest acceleration and arranged them in Table I in order of decreasing acceleration in per cent of gravity. This table lists the acceleration in per cent of gravity, the locality where the shot was fired, the observation point and the energy factor.

It is worthy of note that the first 32 observations in this list were the results of blasting in the tunnels, recorded on the *rocks* of the left abutment or were from blasts in keyways adjacent to the dam, recorded in the left gallery very close to the blasts.

The fifth observation from the top of the table will serve as an example to explain the unusual conditions in the keyway blasts. This blast was set off using 150 pounds of powder, and the *center* of the blast was only 64 feet from the recording seismometer. Actually, much of the powder was closer than 64 feet. The dynamite was laid out in a horizontal plane and the closest sticks were almost under the seismometers (Fig. 3). Under such conditions, rather large intensity figures are to be expected.

The 33rd observation in the table, the first blast from the tunnels to be recorded on the dam, has an acceleration of only 7.5 per cent of gravity. In other words, most of the really significant figures in this tabulation apply only to vibrations passing through rock.

In a brief article[1] by Mr. Neumann and the writer, Mr. Neumann states: "Displacements in the concrete dam were from one half to two thirds those measured in the granite wall at equivalent distances. On the average, there was no outstanding change in the frequency of the dam vibration nor was there any indication of any outstanding oscillation of the dam in its own natural frequency...While there was considerable consistency in the results obtained, the dispersion of the vibrations throughout the granite canyon wall was not generally uniform. There were changes in amplitude and frequency due perhaps in part to the presence of fault surfaces and partly

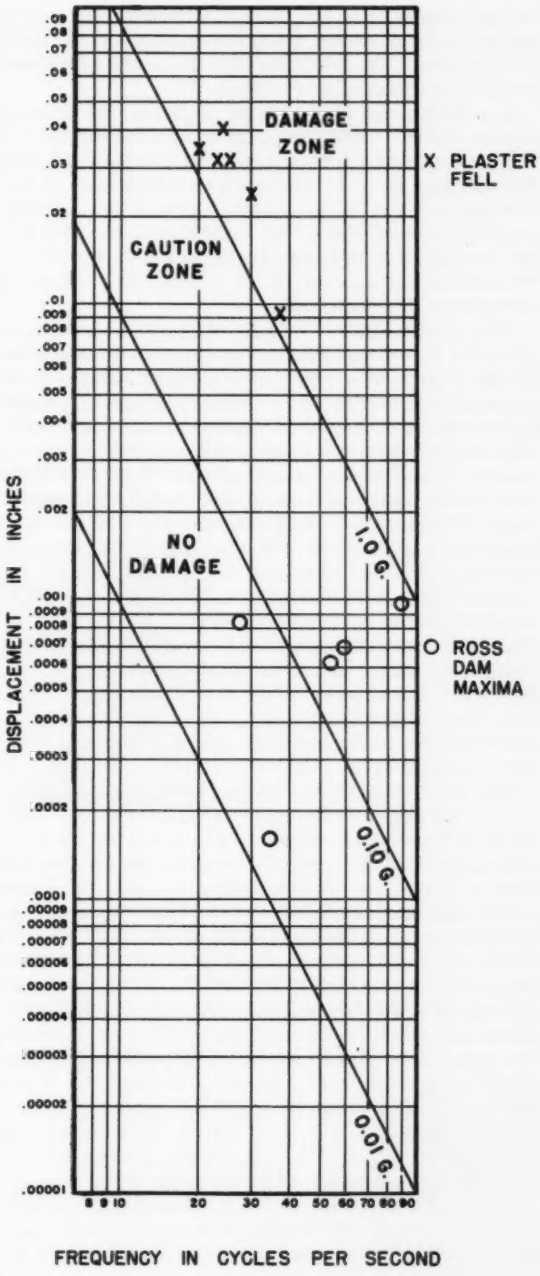


Fig. 6. Frequency-Displacement Chart Showing Extent of Damage by Blasting.

to the complexity of the vibrations themselves, which are made up of waves reflected from the outer surface of the rock, from various discontinuities and transformations of wave types."

In a discussion of the above situation, the present writer states, "Another point of special interest is the frequency of the vibrations. We are familiar with the damage done by earthquake vibrations of low frequency (usually less than 10 cycles per second) especially when the acceleration is known. We are not so familiar with the frequencies in the 20- to 90-cycles per second range insofar as damage to structures is concerned."

Thonen and Windes[2] in their study, *Seismic Effects of Quarry Blasting*, found the frequencies to fall within the 20- to 80-cycles per second range. In an attempt to correlate the possible damage to plaster by blasting with the intensity (in terms of acceleration) of the vibrations, they conducted some experiments on ceiling panels of plaster. Approximately 160 shaker tests were made of 16 panels in 6 buildings. The results of this test were plotted on a frequency-displacement chart, part of which is reproduced in Fig. 6.

This chart is one of a very few in the literature indicating what may be regarded as a danger zone. The chart had to be extended downward considerably so as to include a few of the Ross Dam maxima. The first blast listed on the table of instrumental results was of too high a frequency to be represented on the chart and the accuracy of the figure obtained is very questionable.

The next five figures on the table are plotted on the frequency-displacement chart, (Fig. 6). Only three of these figures (out of 120 observations) fall within the caution zone. Two are in the no-damage zone. A few of the remaining figures could be plotted in the safe zone at the bottom of the chart, but the great preponderance of results could not be entered on the chart, even though the chart is extended down to extremely small displacements. All of the maximum points entered on the frequency-displacement chart are from blasts through rock only, and not through blasts picked up on the dam. The greatest acceleration is from a blast in Tunnel No. 2 and picked up in Tunnel No. 1. All of the vibrations picked up on the dam itself (with the exception of some keyway blasts) fall in the no-damage or safe zone on the frequency-displacement chart.

It is indeed a moot question whether the shaker tests of Thonen and Windes are comparable at all with the vibration measurements at Ross Dam. However, the chart is a very convenient way to summarize statistical data, and perhaps some correlation can be made between the intensity of the vibrations and a danger zone. The real problem is what constitutes the best measure of damage. The chart, as presented, uses acceleration in terms of gravity as the criterion. Perhaps of equal importance is velocity. As Neumann has pointed out, the velocities [2π (amplitude, frequency)] could be represented on the chart by straight lines similar to the lines of acceleration in terms of gravity.

If velocities are used instead of accelerations, then the Ross Dam figures would all fall to a fraction of their former magnitudes and have little relation to the shaker tests represented at the top of the chart. In fact, the Ross Dam velocities are too small to be represented on that portion of the chart published by Thonen and Windes.

In summary, it may be said that from all visible evidence, the first step of Ross Dam was not damaged by blasting. The vibration studies interpreted on the basis of acceleration in terms of gravity suggest that little or no damage would have resulted if the second step had been place.

At present, we do not know just what factors are most responsible for damage to structures; but through the accumulation of factual data, we may be led eventually to an understanding of the true cause of damage.

Acknowledgments

It is a pleasure to acknowledge the work of Mr. Frank Neumann, Chief of the Section of Seismology, U.S. Coast and Geodetic Survey, in supplying records of blast vibrations in terms of accelerations and amplitudes of motion. The writer has profited immeasurably through discussions of these results with Mr. Neumann, and is indebted to him for many suggestions. Messrs. F. Neumann, F. P. Ulrich, and T. H. Pearce of the U.S. Coast and Geodetic Survey are to be congratulated on obtaining so much statistical data under difficult physical conditions.

Mr. Eugene R. Hoffman, Superintendent of Lighting, City of Seattle and Messrs. W. B. Wolfendale, H. B. Faulkner, C. E. Shevling, and E. R. Shindler, engineers of the Department of Lighting have been most co-operative in aiding the studies in every way possible.

References Cited

1. Neumann, Frank and Howard A. Coombs, "Blast-Vibration Measurements Indicate No Danger to Green Concrete in Ross Dam," *Civil Engineering*, Vol. 17, No. 1 (Jan. 1947), pp. 32-24
2. Thonen, J. R. and S. L. Windes, *Seismic Effects of Quarry Blasting*, U.S. Bureau of Mines Bull. No. 442 (1942), pp. 1-83

"The engineering profession is a living thing and requires perpetual regeneration and sustenance to perform the functions to which it is dedicated. Its roots are in engineering education and an intimate bond which provides for constant interchange between education and practice must function in order that it may thrive."—Alfred L. Miller, "Placement in Our Profession," *Jour. Eng. Ed.*, January, 1949.

DIFFUSION IN AGAR GELS

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Foreward: The investigation described below, which was originally reported in the *Journal of the American Chemical Society* in June, 1949, has been conducted as a part of the Pulp Mills research program in the Department of Chemistry and Chemical Engineering. This program is being sponsored by a group of about twenty pulp and paper companies of the state of Washington and has as its objective the development of new knowledge and new processes by means of which more complete utilization of wood can be realized. In the course of study of methods for utilization of the nearly 1,000,000,000 pounds of lignin sulfonates present in sulfite pulpmill waste liquors available in the state of Washington, the authors have devised a relatively rapid method for measurement of diffusion coefficients of lignin sulfonate and of other types of molecules. From knowledge of diffusion coefficients of lignin molecules, some estimates can be made of the size of molecules and this information is important in considering possible fields for utilization of lignin. The authors are all members of the staff of the Chemical Engineering Division of Pulp Mills Research, with Dr. McCarthy in charge.

A. E. Markham

Introduction

The diffusion coefficient of a substance is an exceedingly useful characterization since it may be applied in kinetic analyses of diffusional processes and in addition can be combined with dissymmetry constants from viscosity data to estimate molecular size. However, the determination of diffusion coefficients with adequate precision generally requires painstaking techniques and elaborate apparatus to eliminate dispersion effects other than true diffusion during the actual experiment and to determine the resulting form of the concentration distribution from which the diffusion coefficient may be calculated. There is therefore need for a facile method for determination of diffusion coefficients with moderate precision.

Most of the difficulties inherent in diffusion studies can be eliminated by immobilization of the system observed through the use of gels. While this possibility has been investigated many times in the past, precise results have not been obtained, mainly because of inadequate analytical procedures. Also the effect of the gel structure on diffusion has not been understood, so that interpretation of results obtained is open to question.

Q. P. Peniston

In the present work a new and simple procedure of potentially high precision has been used for analysis of concentration distributions established in the diffusion process. Diffusion studies on several known substances using the above method of analysis, and extraction experiments on agar gels, have provided new information regarding the effects of agar on diffusion and demonstrate the utility of the procedure for determination of diffusion coefficient.

J. L. McCarthy

Viscosity of the Gel Fluid

Extraction experiments on agar gels have shown that their structure is heterogeneous and that a substantial portion (ca. 30 per cent) of the agar investigated consists of water-soluble components, the removal of which follows a first order process. Dissolution and reformation of the residual gel liberates a much smaller amount of additional material for extraction. It is found that the extracted substances possess a high intrinsic viscosity but

lack gelation capacity while that of the residual gel has been increased thus indicating the extractable materials to be in part low molecular weight agar molecules (probably partially hydrolyzed or degraded). These experiments indicate that the fluid in the interstices of the gel possesses a higher viscosity than that due to the sample and supporting electrolyte alone and that this increase in viscosity is probably not linearly dependent on agar concentration.

Procedures for Determination of Diffusion Coefficient

Two general procedures have been used for diffusion studies. The first of these consists of diffusion from a solution of the sample at constant concentration into a cell filled with agar gel. For electrolytic substances a supporting electrolyte (0.02 molar KCl) is used in both solution and gel to eliminate potential gradients. The second procedure is equivalent to free diffusion by the sheared boundary method used for solutions with analysis by the refractive index gradient method. The boundary is formed by casting the sample and solvent gels separately in the diffusion cell. Cells and calculation procedures for both methods are similar, and the scanning technique to obtain the concentration distribution following the diffusion period is identical.

Cells are constructed from quartz microscope slides of usual dimensions with sides and ends of ordinary or colored glass. Internal dimensions are generally 1.5 by 15 by 75 millimeters. Care is taken in preparing the gels to obtain uniformity and to minimize thermal inequalities. The diffusion process is conducted in a thermostat at 25 ± 0.1°C.

Concentration distribution in the cell after the diffusion process is obtained by direct scanning with a Beckman Quartz Spectrophotometer using a fixed wave length. A special carriage with a vernier micrometer rack is used to move the cell across the light path of the instrument. A slit width of 0.5 millimeters is generally used so that optical densities for narrow strips normal to the direction of diffusion are obtained at one-millimeter intervals throughout the length of the cell.

Integration of the differential diffusion equation for the conditions of both procedures leads to probability integrals. With the gel-to-gel method the observed concentration gradient range constitutes a full probability distribution while only half of the probability curve is observed in diffusion from solution-to-gel. In the latter method an extrapolation to the boundary is necessary to obtain the initial or boundary concentration. Also it is found that the soluble substances in the gel have ultra-violet absorption capacity so that a correction must be applied for counter diffusion of these substances. These considerations do not apply to the gel-to-gel method.

TABLE I

GEL-TO-GEL DIFFUSION OF ORANGE II

Detn. No.	Time (days)	Sample Conc. (mg/l)	Agar Conc. (%)	KCl Conc. (M)	Diffusion Coefficient	
					Probability Integral Method (mm^2/day)	Statistical Method (mm^2/day)
49	0.280	100	0.585	0.02	43.0	41.9
52	0.292	100	0.585	0.02	42.1	40.4
72	0.247	100	0.585	0.02	39.4	38.4
82	0.235	100	0.585	0.02	40.6	40.6
99	0.297	100	0.585	0.02	38.2	38.3
81	0.234	100	0.836	0.02	41.2	39.6
80	0.239	100	1.25	0.02	40.0	38.6
79	0.242	100	1.67	0.02	39.9	40.0
71	0.255	100	0.585	None	44.5	42.5
73	0.239	100	0.585	0.05	39.7	40.2
74	0.228	100	0.585	0.20	39.9	39.1
97	0.302	25	0.585	0.02	44.6	40.3
98	0.300	50	0.585	0.02	41.7	39.9
100	0.295	200	0.585	0.02	39.7	37.7
120	0.241	100	0.7	0.02	42.5	42.2
121	0.247	100	0.7	0.02	42.5	41.8
			Mean Value		41.2	40.1
			Average Deviation		1.54	1.14
			Standard Deviation		1.76	1.41

Temperature 25.0± 0.2°C; 2500 Å

Calculation of Diffusion Coefficient

Calculation of the diffusion coefficient and comparison of the form of the concentration distribution with theory can readily be accomplished by plotting observed or corrected concentration ratios C_x/C_0 on probability paper (Fig. 1). In general very good linear plots are obtained in agreement with the theoretical probability integral solutions to the diffusion equation. From the slopes of these lines or their intercepts at particular distances from the boundary the diffusion coefficient may be calculated from tabulated values of the probability integral. The agreement of the form of the diffusion with theory is further substantiated by comparison of this method of calculation with the statistical method of Lamm and Pearson which requires no assumptions regarding the form of the concentration distribution. (See Table I.)

Results with Dyes and Lignin Sulfonates

Results of diffusion experiments by both of the above procedures are reported for tryptophane, Orange II and Azogrenadin S. It is found that the gel-to-gel method yields values of the diffusion coefficient which are 10 to 15 per cent lower than reported values for these substances. The solution-to-gel method, however, yields results which are in substantial agreement with literature values. This difference is believed due to the viscosity of the gel fluid which is presumably constant throughout the cell in the former method but is minimized by counter-diffusion in the region of maximum sample transport for the latter.

No dependence of rate of diffusion on agar concentration was observed for the dyes Orange II or Azogrenadin S, but such dependence was apparent for tryptophane. It is believed that hindrance to diffusion in the latter case results from salt formation with

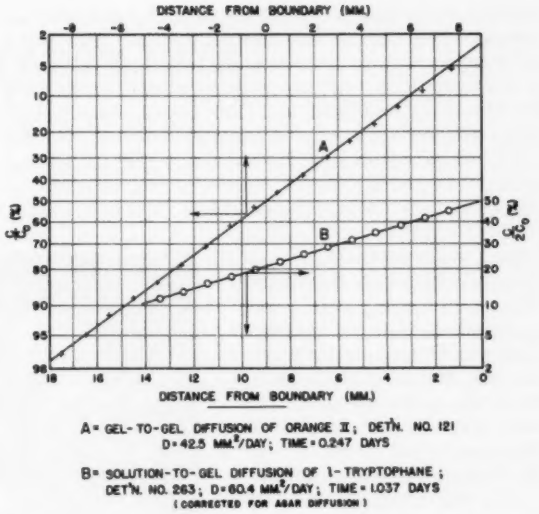
DISTANCE FROM BOUNDARY (MM.)
A
B
DISTANCE FROM BOUNDARY (MM.)
A = GEL-TO-GEL DIFFUSION OF ORANGE II; DET'N. NO. 121
D = 42.5 MM.²/DAY; TIME = 0.247 DAYS
B = SOLUTION-TO-GEL DIFFUSION OF 1-TRYPTOPHANE;
DET'N. NO. 263; D = 60.4 MM.²/DAY; TIME = 1.037 DAYS
(CORRECTED FOR AGAR DIFFUSION)

Fig. 1. Probability Plots of Diffusion Data

carboxyl or sulfate groups in the agar molecules. Extrapolation of data for tryptophane to zero agar concentration yields a result in close agreement with the reported diffusion coefficient in aqueous solution.

The effect of imperfection in the original boundary has been investigated by studies on a lignin sulfonic acid fraction. This effect is found to be considerable for short diffusion times or slowly diffusing substances. The effects of concentration dependence and of polydispersity on the form of the concentration distribution are discussed and results of diffusion of a mixture of two lignin sulfonic acid fractions of widely different diffusion coefficients are compared with theory.

Engineers Excel in Cultural Tests

A modern concept of scholarship on the part of the University of Washington chapter of Phi Beta Kappa, and the effective development of the Division of Humanistic-Social Studies in the College of Engineering may be held jointly responsible for the fact that out of 85 students elected to membership in the chapter last May, 21 were enrolled in the College of Engineering. To qualify for membership in this progressive chapter of the oldest honorary fraternity in the United States, an engineering student not only must have a very high grade point in his courses but must pass a comprehensive test in six fields: current social problems, history, literature, science, fine arts, and mathematics.

Outstanding records in the examinations were made by Glenn D. Elmer, an M.E. student, who took second place among the 85 with a total centile rating of 5.92, Leonard A. Back (E.E.) and Howard T. Tupper (Ch.E.), who tied for third place with 5.88, and Robert R. Larson (A.E.), who was fourth with 5.87. The highest score, 5.94, was made by a psychology major.

This significant trend at the University of Washington, although shattering the long-cherished engineering tradition of the "rough-necked he-man," goes far to prove that the University is doing its part to fill the demand of modern industry for engineers who are well rounded citizens as well as competent technologists.

The primary objective of the humanistic-social courses for engineers at the University of Washington is not to lay down a barrage of endless unrelated facts but to stimulate the students' intellectual curiosity in fields outside their professional interests; its secondary purpose, to trace throughout the ages the interrelationships of man's endeavors and accomplishments in order to plot his place in the modern cosmos.

DIELECTRIC HEATING

W. R. Hill

Associate Professor of Electrical Engineering

This report describes some experiments in high-frequency dielectric heating performed under the auspices of the University of Washington Engineering Experiment Station. The project began in the Fall of 1947 with Mr. T. R. Stuelpnagel and Mr. C. Y. Lee as research fellows in electrical engineering, and Mr. H. Schuyten of chemical engineering who was later followed by Mr. J. A. Buckham of the same department. After the one-year general study of the dielectric heating phenomenon a specific application was chosen for study. F. N. Grimsby, Research Fellow in Chemical Engineering and J. W. Caspers and P. Y. Yu, Research Fellows in Electrical Engineering, are carrying on the present research activities of the project.

Fig. 1. Professor Hill (center), J. A. Buckham (left), and T. R. Stuelpnagel, with Experimental Setup

Properties of Dielectric Heating

First known as something to be avoided in the design of high-power radio equipment, the present uses of dielectric heating range from plywood gluing to the novelty cooking of hot dogs. The design approach in many of these applications is rather empirical; the purpose of this study was to undertake an analytical experimental study of the process to compare the theoretical and actual behavior of dielectric heating.

Dielectric heating is but one of two types of heating produced by the application of radio-frequency energy to a material. The other type, called induction heating, occurs through the formation of circulating eddy currents in a conducting material (a metal) placed in a coil of wire carrying a high-frequency alternating current. This heating system, which operates best at frequencies below one megacycle per second, provides an excellent means of locally heat treating metals and, in conjunction with proper flux and brazing wire, produces an exceptionally neat brazing job.

Dielectric heating, on the other hand, heats nonconducting materials such as wood and the plastics. For this purpose the material, usually called the work, is placed between a pair of metal plates connected to a high-frequency generator capable of supplying several kilowatts of power at a voltage of several kilovolts. This heating method requires a frequency of 10 megacycles or more; the Federal Communications Commission has set aside the frequencies of 13.56, 27.12, and 40.68 megacycles for commercial operation of dielectric heating equipment. Even higher frequencies are now being employed, but the maximum frequency is limited by the fact that the physical dimensions of the work must not ordinarily exceed about one-eighth wave length of the radio-frequency supply. For example, heating a piece of material three feet long requires the use of a frequency below 40 megacycles unless special arrangements are employed for distributing the energy evenly.

The advantage of dielectric heating lies in the fact that the electric field generates heat in the interior of the material and can rapidly raise the temperature. This is an important advantage because electrical nonconductors also conduct heat poorly and an attempt to raise the interior temperature rapidly by the application of external hot

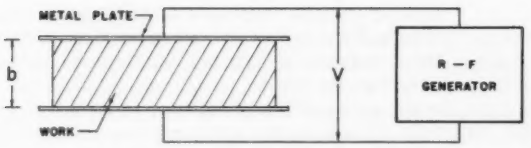

Fig. 2. Simple Dielectric Heating System

plates may scorch the surface before the interior can reach the desired temperature. With an applied temperature low enough to prevent surface overheating, the thermal time lag may seriously delay a manufacturing process. For this reason the time saved by dielectric heating may make its use economical despite the relatively high cost of energy in radio-frequency form.

The following expression for the heat developed in a nonconducting material exposed to an alternating electric field shows the need for both high voltage and high frequency to produce effective heating:

$$W = 0.55\, fE^2 (\cos\theta)\, \epsilon' \qquad (1)$$

where

W = heat liberated in the work (watts per cc)
f = frequency of applied power (megacycles per sec)
E = effective electric field intensity (kilovolts per cm)
$\cos\theta$ = power factor of the heated material
ϵ' = the dielectric constant of the material.

Since the power factor and the dielectric constant are both factors of the heated material, they are commonly combined into a single factor called the *loss factor*, given symbol ϵ''. This factor varies from less than 0.01 for low-loss plastics to 0.5 for a moist piece of wood.

For the relatively simple arrangement of Fig. 2 showing a slab of material between two parallel plates spaced distance b cm apart with an alternating potential of V kilovolts impressed, the field intensity becomes simply the total voltage divided by the plate spacing. This makes the equation for the power loss per unit volume

$$W = \frac{0.55\, fV^2\epsilon''}{b^2} \qquad (2)$$

As an illustration of the need for high frequency, Eq 2 shows that a frequency of 23.5 megacycles will produce a heat liberation of 5 watts per cc with 5 kilovolts applied to a one-inch thick sample having a loss factor of 0.1. The use of higher voltages reduces the required frequency but electrical breakdown of the surrounding air limits the maximum allowable voltage before sparking occurs.

Problems in Dielectric Heating

The simple and easily derived expression of Eq 1 for the heat release in a body placed in an alternating electric field suggests that the problem of forecasting the behavior of a typical dielectric heating cycle may not be difficult. Unfortunately the heating process also involves a rather complex heat-flow problem which is solvable in the simplest cases of one-dimensional heat flow produced by a uniform electric field acting upon a smooth slab of material, but which becomes hopelessly complex for even relatively simple shapes involving two- or three-dimensional flow and nonuniform heating fields. Added to this are the complications of thermal films and the even more difficult problem of transient behavior to solve for information regarding the time variation of temperature.

The literature is well stocked with articles on the subject of dielectric heating, both theoretical and of a practical applied nature, but Brown, Hoyler, and Bierwirth of RCA have contributed an excellent book[1] which summarizes the subject in a very complete way. This book not only develops much of the complex mathematical theory required for even the simplest heating arrangements, but it also discusses practical applications and provides many useful curves to save work in computing temperature distributions in heated materials.

There was considerable doubt at the beginning of the project as to the applicability of much of the theory to practical heating problems. Rumors of unexpected and unusual results obtained with dielectric heating were common, but there was little in the literature to indicate the accuracy of the experimental work reported, and the methods of voltage and temperature measurement were seldom discussed at all. Consequently the following questions were proposed for the first phase of the dielectric heating project:

(1) Can the high alternating voltage applied to the sample be accurately measured?
(2) What is an accurate way of observing the temperature of a material undergoing dielectric heating?
(3) Are the assumptions made in the theoretical analysis valid?
(4) Can the thermal and electrical properties of a material be measured accurately enough to permit predictions for simple problems?

Experimental Verification

The experimental work accomplished by the project

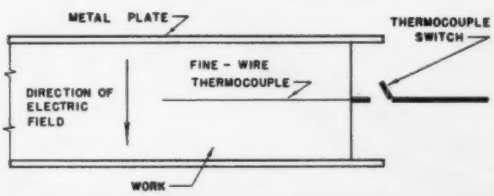

Fig. 3. Section Showing Installation of Thermocouple to Avoid Interference with Electric Field

fellows gives the following answers to the questions proposed:

(1) The radio-frequency voltage of a grounded electrode system can be accurately measured and provides one of the best means of controlling the heating cycle. The more difficult problem of measuring the plate-to-plate voltage of an ungrounded system has not yet been attacked.

(2) Properly inserted thermocouples provide an accurate means of observing the temperature of the work without appreciably affecting the temperature distribution. The thermocouples must be operated with a quick operating switch to take readings with the high-frequency power momentarily turned off.

(3) The assumptions made in most theoretical analyses neglect the variation of loss factor with temperature. With this inclusion the experimental measurements check the theoretical analysis very well.

(4) It is possible to measure the thermal and electrical properties of a material and from these to accurately predict the heating cycle for simple physical arrangements. For more complex physical systems these measurements, together with the principle of similitude, permit an extension of the semi-empirical data with which one must often be satisfied.

Early in the project it was decided to attack first the problem of making the thermal and electrical measurements, and then to set up a simple dielectric heating problem to correlate these measurements to the published theory. To this end Mr. H. Schuyten constructed equipment for measuring the thermal properties of materials and then carefully determined the thermal constants for Lucite, a material chosen for the test case because of its convenient thermal, electrical, and mechanical properties. His thesis[2] reports the results obtained.

Simultaneously Stuelpnagel started work on an accurate high-voltage, high-frequency vacuum-tube voltmeter and Lee began the design of a Q-meter for determining the electrical properties of sample materials. The vacuum-tube voltmeter problem was solved by the construction of two different types of meters, each calibrated by a different process and then checked against one another. The meter finally constructed covered a voltage range extending to 4 kilovolts and gave readings accurate to within 3 per cent independent of frequency from 1 to more than 20 megacycles. Such meters do not seem to be

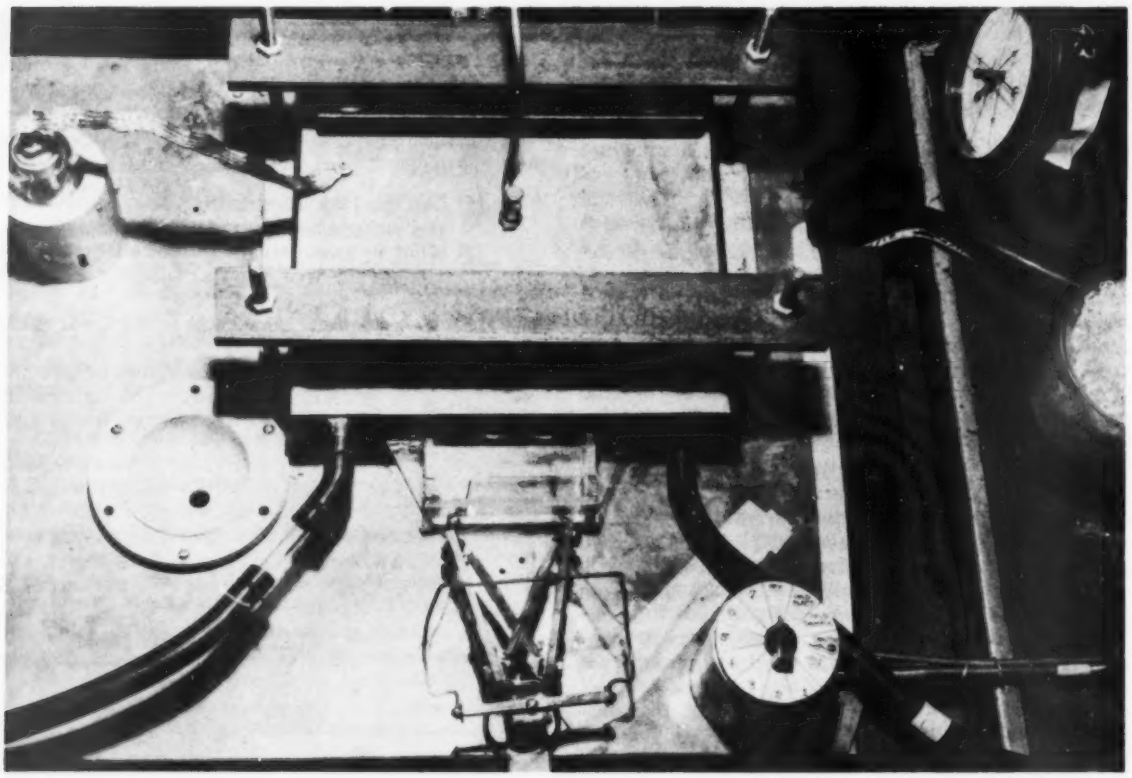

Fig. 4. Detail of Final Experimental Arrangement

commercially available as yet.

Upon completion of the thermal measurements and the development of the voltmeter, Stuelpnagel, assisted by Buckham, set up the test problem consisting of a block of Lucite placed between two parallel water-cooled electrodes (Fig. 1). Their joint thesis,[3] upon which much of this discussion is based, fully describes the techniques developed and draws the comparisons here suggested. The attempt, of course, was not to represent any particular practical application, but to operate with the simplest possible heat-flow problem for the purpose of correlating the theory and application. Since a good check was obtained, this also provided information regarding the accuracy of the temperature-measuring system.

Temperature Measurement

The temperature at selected points within the work is probably the most important information obtainable for a dielectric heating study. Many articles mention temperature measurement but they usually do not include a specific discussion as to the system employed or its limitations.

The requirements of a good temperature measuring system are (1) it must not appreciably disturb the electric field or change the rate of heat production in the sample, (2) it must not affect the heat flow in the sample, (3) for many laboratory tests the accuracy must approach 0.1°C, and (4) temperature readings should preferably be made with the radio-frequency power applied.

The final choice for making accurate temperature measurements consisted of a fine wire thermocouple inserted into the sample and connected to a potentiometer through a disconnecting switch. Fig. 3 shows a simplified sketch of the arrangement for a single thermocouple. Making the thermocouple of fine wires (B&S No. 30 gage or smaller) and placing it perpendicular to the direction of the electric field minimizes the field distortion. A theoretical analysis for the distortion produced by an isolated long wire in a homogenous medium between a pair of plane-parallel plates shows that the effect of the distortion exactly cancels out in the net effect on the average heating in the vicinity of the thermocouple. Fortunately, for most simple arrangements such as that of Fig. 3, placing the thermocouple perpendicular to the electric field also makes it perpendicular to the direction of heat flow and minimizes errors that might occur if the relatively good conductor intersected areas at different temperature levels.

Since theoretical analysis indicated the need for an isolated wire to eliminate field distortion errors it was necessary to terminate the thermocouple at the surface of the work sample and connect to the potentiometer circuit only during the few moments necessary to read the temperature. While there was some hope that this might be done with the radio-frequency power applied, it was found, as feared, that the current flow induced into the thermocouple

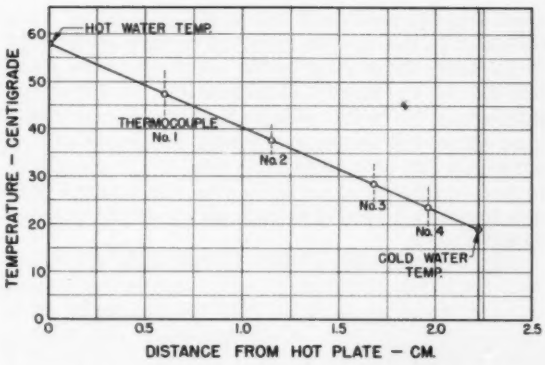

Fig. 5. Temperature Distribution in Sample with One Hot and One Cold Surface

circuit often exceeded 0.2 ampere which rapidly heated the thermocouple wires and made accurate readings impossible. Temporarily removing the high-frequency power for the few moments required to take the temperature readings, however, made it possible to exceed an accuracy of 0.1°C.

Other practical details involved shielding of the potentiometer connections, installation of a filter to reduce the stray radio-frequency current in the potentiometer, and construction of a quick-acting switch that completely isolated the potentiometer leads from the thermocouples while applying the heating power. Trouble with thermal emfs caused by the temperature gradient at the switch contact was eliminated by isolating the terminal pins from the sample to reduce the temperature difference between the pins and the switch contacts. Fig. 4 shows some of these details.

Theoretical and Experimental Correlation

After several initial experiments to solve some of the measurement problems, the final experimental setup shown in Fig. 4 was constructed. This consisted of a sample of Lucite 7/8-inch thick by 12 inches square carefully cut in two at the middle for the insertion of thermocouples at various depths in the plastic. The couples were installed in milled slots just wide enough to contain the wires, after which the sample was restored to a single piece by a glue made of Lucite and a solvent. This located the thermocouples directly above one another in a solid plastic sheet.

The specific problem chosen for this study was that of a dielectrically heated sample placed between two parallel electrodes held at constant temperature by water cooling. The sample was relatively thin compared to its other dimensions to ensure one-dimensional heat flow at the center and thus simplify the heat-flow problem. To avoid the variable interfacial temperature drops that inevitably occur between water-cooled plates and the sample and which caused difficulty in the initial runs, the final arrange-

ment actually employed hollow plates with one surface next to the sample removed to permit high velocity water circulation on the plastic surface. Even this did not completely eliminate film heat transfer difficulties, but it did reduce them to a nearly negligible value. For an actual practical dielectric heating arrangement, of course, heat flow to the electrical plates may not even be desirable; the attempt here was to set up a simple system with everything accurately known.

Fig. 5 shows the results of a heat-flow test made with hot water circulating on one side of the sample and cold water on the other. The thermocouple readings show a beautifully straight-line temperature distribution. This indicates that the temperature of the sample surface closely approached the circulating water temperature and that surface films interposed a negligible temperature drop. More involved transient tests with suddenly applied surface temperature further checked the validity of assuming one-dimensional heat flow.

Further tests of the temperature distribution with applied dielectric heating also fitted the theoretical computations except for a small progressive error at the higher temperatures; a careful analysis led to the belief that an increase in the loss factor with temperature accounted for this discrepancy. The complete analysis of the situation included a new solution of the heat-flow equation to include variable loss factor, and a recheck of the data to fit the improved theory.

Further work this year on the measurement of loss factors over a wide temperature range shows that the loss factor does indeed increase with temperature and that the approximation of constant loss factor is often not a valid one.

Present Activities

The present activity of the project centers on the study of a particular application of dielectric heating — that of the effect of dielectric heating and electric fields on the behavior of catalysts. Some work of this type has been reported in the literature and it appears that dielectric heating may offer improvement over conventional methods because of the more uniform heating obtainable and because of a possible effect of the electric field upon the catalytic reaction.

To that end F. N. Brimsby, a chemical engineering fellow, has made a study of suitable reactions and catalysts for the process, and two electrical engineering fellows, P. Y. Yu and J. W. Caspers, have constructed apparatus for measuring the loss factor and dielectric constant of materials over a temperature range extending to 500°C. Alumina, chosen as a suitable catalytic agent, shows large increases in loss factor at the higher temperatures although the dielectric constant remains fairly steady.

To eliminate some of the variables, the first experiment will employ an arrangement of the catalyst designed to observe the effect of the electric field without attendant dielectric heating. As a second step the reaction may be studied with both dielectric heating and the electric field. In this way it will perhaps be possible to separate the two effects and to discover the reason for any improved catalytic activity found.

References

1. Brown, G. H., C. W. Hoyler, and R. A. Bierwirth, *Theory and Applications of Radio-Frequency Heating*, D. Van Nostrand Co., New York, 1947.
2. Shuyten, H. S. "A Study of the Temperature Distribution in Conductive and High-Frequency Dielectric Heating," M.S. thesis in Chemical Engineering, University of Washington, 1948.
3. Buckham, J. A., and T. R. Stuelpnagel, "A Correlation of Theoretical and Experimental Temperature Distribution in High-Frequency Dielectric Heating," M.S. thesis in Chemical and Electrical Engineering, University of Washington, 1948.

WASHINGTON COUNCIL OF RESEARCH LABORATORIES

Membership in the Washington Council of Research Laboratories, recently organized for the purpose of acquainting the public with the local facilities qualified for research on their scientific problems, is limited to firms, individuals, and institutions, generally provided with laboratories, which will undertake scientific research for clients.

Officers of the Council include Dr. T. L. Swenson, Food Chemical and Research Laboratories, Seattle, chairman, Mr. Tom Williams, Northwest Laboratories, Seattle, vice-chairman, and Mr. W. W. Philbrick of the University of Washington Engineering Experiment Station, secretary-treasurer.

The membership committee, headed by Dr. H. K. Benson, Professor Emeritus of Chemical Engineering and Director of Research, Laucks Laboratories, Seattle, includes Mr. Joseph Drumheller, Drumheller Analytical Laboratory, Spokane, and Chairman of the Board of Regents of the University of Washington, Mr. A. J. Norton, Seattle, Prof. E. B. Parker, Director, Division of Industrial Services, Washington State Institute of Technology, Pullman, and Mr. Robert Lent, Lambert-Lent Laboratories, Seattle.

The Council is now engaged in preparing a directory of its members, for distribution to the public, outlining the facilities and specialties of its members.

ELECTROFORMING IRON*

Irving Larson

Research Fellow in the Engineering Experiment Station

R. W. Moulton

Associate Professor of Chemical Engineering

G. L. Putnam

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Introduction

Although electroforming as a practical metal-forming method is relatively new,[1] the basic process itself is not. Electrotyping, the process used for the printing of most books and involving electrodeposition of copper on a wax mold, dates back over one hundred years. The first success in electroforming, except for electrotyping, was apparently in the manufacture of boiler tubes. About thirty years ago, iron tubes were electroformed in Grenoble, France;[2] Milford, Connecticut;[3] and Niagara Falls, New York.[4] Probably because of lack of understanding of the fundamental variables involved, these plants are not in operation today.

World War II hastened the development of electrolytic iron. The services demanded some unusual parts which could be made in no other way; the facilities of conventional forming methods were overtaxed; costs were only a secondary consideration. As a result of the accelerated development work, techniques were improved and costs reduced so that now electroforming is finding a definite place among the metal-forming methods. Not only can intricate shapes be produced without machining, but the method has the further advantage that small-sized plants of low capital cost are feasible.

EXPERIMENTAL DETAILS

Electrolysis

The ferrous chloride electrolyte was placed in a 10-gallon earthenware crock. Heating was accomplished with one 2500-watt and one 300-watt nichrome resistance element placed inside individual 19-inch by 2-inch diameter test tubes and immersed in the electrolyte. To keep the temperature constant the 300-watt heater was controlled by a relay and thermoregulator, and the main heater operated slightly below the required power necessary to maintain the desired temperature. Nickel bus bars were used. The cell was equipped with a transite cover, stirrer, and thermometer, and had suspended within it an asbestos cloth bag containing activated charcoal. The electrolyte level was kept constant by a constant level device.

R. W. Moulton

Four cathodes were plated on each side in each run giving eight specimens for examination and test. Two cathodes were hung from each of two cathode bus bars giving two parallel circuits through which the current density could be varied, as shown in Fig. 1.

Materials

The bath contained 100 ± 15 g.p.l. of technical ferrous iron as the chloride, and 100 ± 5 g.p.l. technical calcium chloride.[5] For small variations in concentrations the properties of electrolytic iron are not a function of calcium chloride or ferrous chloride concentrations.[6] Calcium chloride was determined by Scott's procedure,[7] in which iron is precipitated with ammonium hydroxide before calcium oxalate precipitation. Ferrous iron was determined by titration with potassium dichromate, diphenylamine being used as an internal indicator.[7] Ferric iron was determined by the ammonium thiocyanate method[7] using a Klett-Summerson colorimeter.

G. L. Putnam

A most critical variable in the electrodeposition of

*Condensed from "Physical Properties of Iron Deposited from Chloride Baths," by I. Larson, R. W. Moulton, and G. L. Putnam, *Jour. Electrochem. Soc.*, Vol. 95, No. 4, April, 1949.

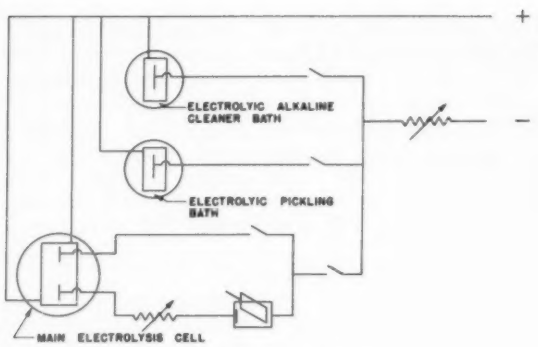


Fig. 1. Wiring Diagram

iron is the purity of the bath, as shown by Stoddard[6] and McFayden.[8] Only by cleaning the bath by boiling with iron dust and by filtering through activated carbon could consistent results be obtained. After the treatment with iron dust, ferric chloride was added to bring the ferric ion concentration to the desired value. Iron carbides react with acids to give liquid and solid hydrocarbons,[9] and presumably a similar reaction takes place at anodes containing iron carbides. In order to maintain the electrolyte at the desired degree of purity, it was found necessary to suspend in the electrolyte asbestos cloth bags filled with activated carbon so that the electrolyte would be continuously purified during cell operation.

Armco iron strips 14.5 inches by 0.75 inch by 0.057 inch thick (14 gauge) were used as the anodes; the cathodes were of mild steel 12 inches by 0.75 inch by 0.03 inch (20 gauge). All electrodes were cleaned as specified by Engel.[10] The entire cathode was immersed, but the upper portion of the anode projected above the solution.

Tests of Physical Properties

The samples plated rather heavily around the edges and in order to produce a uniform cross section for the tensile tests, the edges were cut off with a shear. This treatment was severe enough in practically all cases to lift up one edge of the plate from the base metal, so that the electrolytic deposit, approximately 0.03 inch thick, could be stripped and tensile tests made on the plate itself. Tensile tests were made by standard methods,[11] the per cent elongation readings being taken on a basis of a two-inch length. Hardness measurements were made with the Barber-Coleman hardness tester. Bar-Col readings are readily converted to equivalent Brinell hardnesses.[12]

DISCUSSION OF RESULTS

Current Density

The effect of current density at 90°C. and a pH of 0.9 is shown in Fig. 2. Increasing the current density

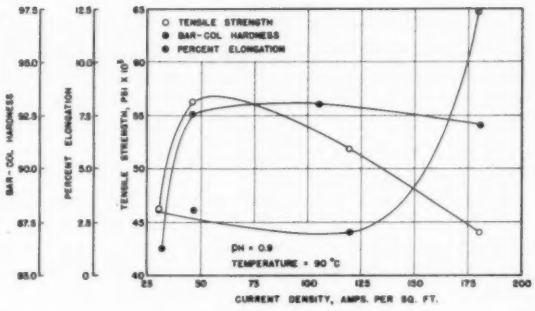


Fig. 2. Effect of Current Density on Iron Properties

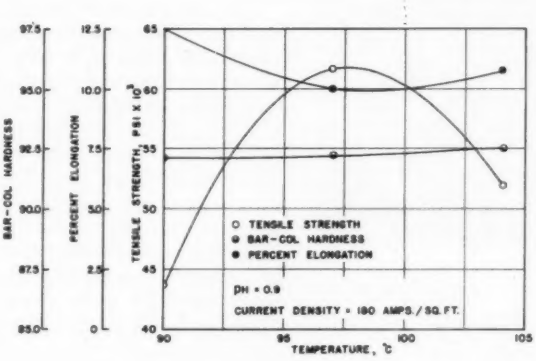


Fig. 3. Effect of Temperature on Iron Properties

had little effect on the hardness, caused a slight reduction in tensile strength, and increased the percentage elongation.

Temperature

The effect of temperature under the experimental conditions is shown in Fig. 3. The highest tensile strengths were obtained at about 97°C.

pH

Probably pH is the most critical variable investigated (Fig. 4). At 104°C., decreasing the pH considerably increased tensile strength as well as per cent elongation, in confirmation of the results of Wallace and Iler,[5] but not in agreement with Stoddard,[6] who reports an optimum pH of about 2.0.

Ferric Iron Concentration

The effect of ferric iron concentration is shown in Fig. 5. Most of the workers in the past have tried to keep the ferric iron concentration as low as possible,[6,13] but the U. S. Rubber Co.[5] reports that moderate ferric iron concentrations are desirable. Increasing the ferric iron concentration from 0.04 to 0.74 grams per liter considerably increased the tensile strength.

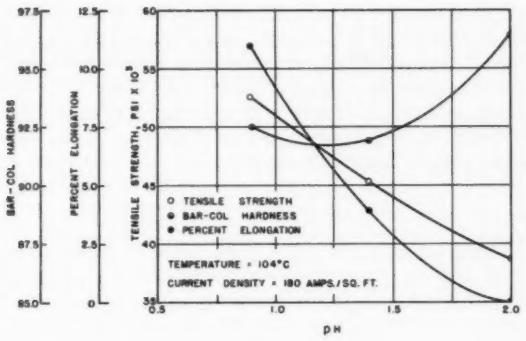


Fig. 4. Effect of pH on Properties of Iron

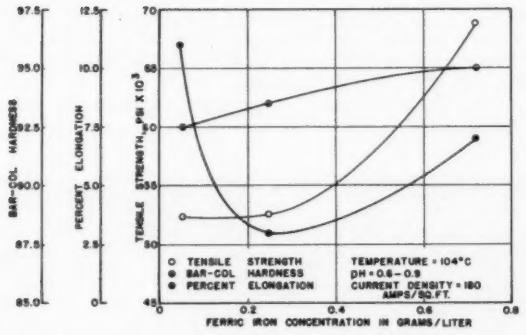


Fig. 5. Effect of Ferric Iron Concentration

The data show a better combination of tensile strength and elongation by increasing the ferric iron concentration to at least 0.72 grams per liter.

Grain Structure

A photomicrograph of one of the specimens is shown in Fig. 6. In this case it appears that the base metal may have influenced the orientation of the electrodeposited iron to a thickness of about 150,000 A.[14] As shown by Storey,[15] the electrolytic iron was found to pass through a transition from typical needle to conventional ferrite grains at 910°C.

Conclusions

1. Of the variables investigated, change in pH produces the most pronounced effect on the physical properties of iron deposited from the chloride bath.

2. At the optimum pH of 0.6-0.9, increasing the ferric iron concentration to a value at least as high as 0.72 grams per liter gives a better combination of tensile strength and elongation than do lower ferric iron concentrations.

3. Over the range of 25 to 180 amperes per square foot, at a temperature of 104°C., the effect of current density is not pronounced, confirming the conclusions of Stoddard.[6]

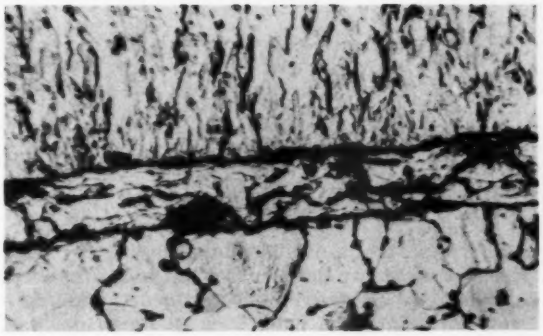


Fig. 6. Iron as Deposited. Nital Etch. x 300

References

1. Bull, Bishop, Orbaugh, and Wallace, Ind. Eng. Chem., News. Ed. **17**, 461-4 (1939).
2. Escard, Elec. Rev. **76**, 610 (1920).
3. Belcher, Trans. Am. Electrochem. Soc. **45**, 455-74 (1924).
4. Anonymous, Iron Age, **116**, 675-9 (1925).
5. Wallace and Iler (to U. S. Rubber Co.), U.S. 2, 316, 917, April 20, 1943; ibid, Brit. 543, 137, Feb. 11, 1942.
6. Stoddard, Trans. Electrochem. Soc. **84**, 305-18 (1943).
7. Furman, "Scott's Standard Methods of Chemical Analysis," 5th Ed. Vol. 1, New York, D. Van Nostrand Co. (1939), pp. 209, 473, 486.
8. McFayden, Trans. Faraday Soc. **15**, Part 3, 98-133 (1920).
9. Putnam and Kobe, Chem. Rev. **20**, 139 (1937).
10. Engel, Iron Age **156**, No. 10, 70-9 (Sept. 6, 1945).
11. American Society for Testing Materials, A.S.T.M. Standards 1944, Ferrous Metals, pp. 1223-7, A.S.T.M. Designations A 245-44T and A 246-44T.
12. Williams, A.S.T.M. Proc. **43**, 839 (1943).
13. Thomas, Trans. Electrochem. Soc. **80**, 499-507 (1941).
14. The Electrochemical Society, "Modern Electroplating," New York (1942), p. 48.
15. Storey, Trans. Am. Electrochem. Soc. **25**, 489 (1914).

"Now that more scientists are being trained, the chief need is . . . to widen the field of affairs in which the scientist is able and expected to take an interest. Above all, we must, by education and experience, train a greater number of men to have that broad knowledge and understanding necessary for co-ordinating the manifold activities of complex organizations in which science now plays too important a part to be incorporated only at secondhand through the minds and advice of others." —E. Smith, *Research*, June, 1949.

TESTS FOR SHEAR RESISTANCE OF SOILS

G. Bryce Bennett

Research Fellow in the Engineering Experiment Station

The resistance of soils to shearing forces is probably the most important of all soil properties to foundation, highway, and earthwork engineers. Every hill, mountain, river bank, and man-made cut and fill owes its steepness and height to the shearing resistance of the material of which it is made. Any material lacking shear strength is a fluid and flows until its surface is level. If the shearing stress in a body exceeds its shear strength, the body fails. These failures in soils may cause a slide, collapse of a retaining wall or sinking of a structure into the ground.

Tests for directly evaluating the shearing strength of soils are difficult to perform and to interpret. Moreover facilities for such tests are not readily available to many engineers and organizations who would find use for the resulting data. It is in an attempt to find and correlate shear resistance with some more simple tests that research on shear strength of soils is being carried on at the University of Washington. The investigation, known as Engineering Experiment Station Project No. 5, was conducted jointly by the writer and Mr. Harold Mason, former research fellow in the Engineering Experiment Station, under the supervision of R. G. Hennes, Professor of Civil Engineering.

Shearing strength of soil, it is believed, can be related to other and more easily measured physical

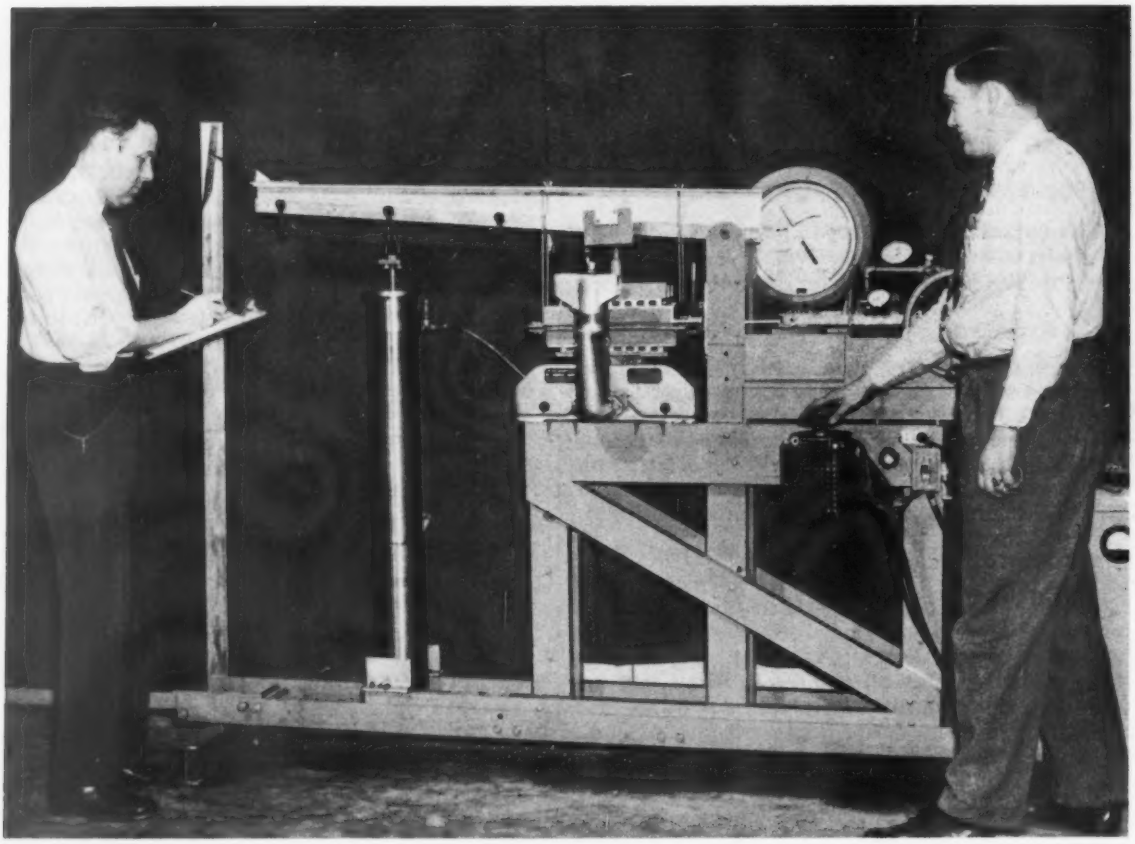


Fig. 1. G. B. Bennett (left) and Harold Mason with the Large Shear Machine

characteristics. Shear strength of any given sample may be composed all or in varying proportions of either cohesion or internal friction. These two components of shear resistance may be considered independently. In granular soils with no binder it is known that the entire resistance to shear is from internal friction. Cohesion on the other hand is the predominant characteristic of plastic clays.

To investigate shear resistance we must first investigate the component parts and then combine the results in an attempt to resolve the more difficult condition where both factors are present together. The portion of the research program presented here is a part of the investigation of internal friction. More specifically it is the effect of grain size and particle shape on internal friction.

Since granular soils have no apparent cohesion, tests were made on this type of material. Two kinds of aggregate were selected to give maximum contrast of particle shape and surface texture. One sample was rounded river gravel in which nearly every stone was rounded and smooth. The other sample was of crushed basaltic rock; every particle in this case was extremely rough and angular.

Each of these samples was sieved into various grain sizes. Tests in a specially constructed large size direct shear machine (Fig. 1) were made on each size to determine the corresponding shear resistance. The standard direct shear machine, having a shear box of approximately 10 square inches in area, is too small for testing the larger granular material. Therefore the large shear machine shown in Fig. 1 was developed. It has a shear box of 72-square inch area and is large enough to test grain sizes up to 1-inch diameter.

In this direct shear machine vertical loads are applied by compressed air acting on a piston. The air chamber is large enough to permit expansion of the sample during the test with little change in normal pressure. The upper half of the sample box is restrained while the lower half is pulled out by a 3000-pound capacity hydraulic testing machine.

The results of this series of tests look very promising. Approximately 85 separate test runs have been completed on the river gravel and the crushed rock.

Fig. 2 shows the results of these tests. A definite relationship between grain size and shearing resistance has been established, an especially significant result which, it is believed, has not been shown before. Curves of Fig. 2 also show the relationship between internal friction and grain shape. For most of the sizes the values of internal friction were greater for crushed rock than for the river gravel. However for the large sizes (above about one-half inch) the values for the gravel were about the same

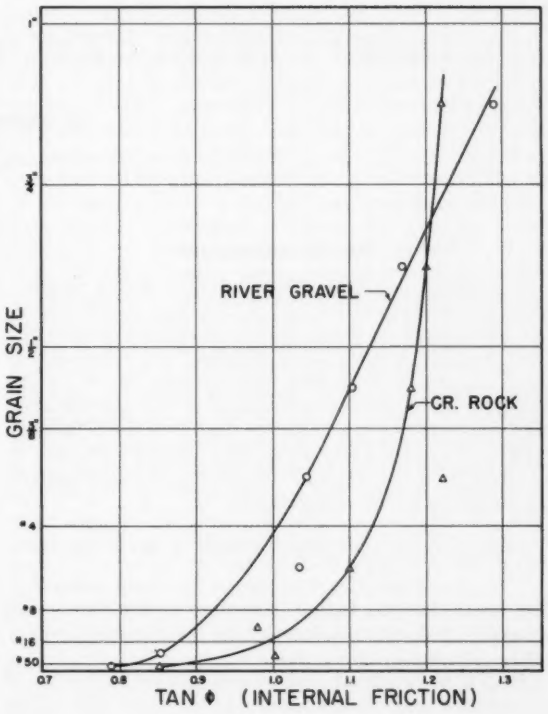


Fig. 2. Relationship of Grain Size and Shearing Resistance for Granular Soil

and in some cases slightly higher than those for the rougher textured crushed rock. Further investigations will be required to determine reasons for this unanticipated result.

As a check on values obtained by use of the direct shear apparatus a series of tests will be made with a triaxial compression machine. A special large size triaxial machine is now being constructed for this purpose.

Tests to determine effect of different grading will be made using the direct shear apparatus. Some of these results will also be checked using the triaxial compression device.

Cohesion effects will be evaluated by the unconfined compression test of suitable clays.

This research, if carried to a successful conclusion, will furnish information of the highest practical value and will be a definite contribution to the art of soil mechanics engineering. It will permit evaluation of the angle of internal friction (i.e., shear strength) of soils and aggregates, without the use of expensive laboratory equipment and will therefore be available as a common tool for the use of all engineers having average field testing equipment.

ENGINEERING GEOLOGY OF WEST SEATTLE

J. Hoover Mackin

Professor of Geology

General Statement

In accordance with the discussion at the conference of representatives of the City Engineer's office, the committee of West Seattle residents concerned with the Alki Avenue slide problem, and members of the University of Washington faculty, work on the mapping of foundation materials in the Seattle area was started in West Seattle, and has been largely confined to that district to date. Much remains to be done, and the results outlined here may need to be modified in the final report.

General Geologic Relationships in West Seattle

The accompanying diagrammatic cross section of the West Seattle hill is intended to illustrate the general geologic relations of the larger sedimentary units that make up the hill:

Unit C consists of clay, sand, gravel and peat. It is exposed only at low levels on the east side of the West Seattle hill and is not directly involved in West Seattle engineering geology problems. It is mentioned here because it is probably the same age as the sequence of glacial materials that make up the bulk of Beacon Hill to at least 200 feet above sea level, the point being that these two hills, side by side and similar in surface form, are altogether different in the age and characteristics of the underlying glacial deposits.

Unit B makes up at least 90 per cent of the West Seattle hill. The lower part of the unit consists chiefly of thick and thin bedded blue clay and silt, interbedded with lenses and sheets of fine to medium grained sand. At a poorly defined altitude varying from about 110 to about 160 feet above sea level the clay grades upward into medium to coarse grained brown sand (B 2) which continues to the top of the hill. The brown sand locally contains minor and discontinuous layers of silt and clay.

Unit A is a veneer of glacier till, averaging about 10 feet in thickness, that forms an essentially continuous mantle on the top and flanks of the hill except where removed by wave or stream cutting or by artificial excavations. It was deposited directly by ice during the last glacial period and long post-dates the flat-bedded water-laid sediments of Unit B. The characteristics of the till vary from place to place depending on the nature of the subjacent materials over which the ice moved. Thus, where the till rests on clay on the lower hill slopes it is a dense hardpan, while on the upper slopes and the top of the hill it consists largely of sand and is much less compacted.

General Ground-Water Relationships

The ground water in the West Seattle hill is supplied wholly by precipitation on the hill itself—there is no reason to believe that there is any artesian flow from water-bearing strata in depth. Precipitation on the hill is partly lost by transpiration by plants and direct evaporation, and partly by direct runoff; the remainder sinks into ground to form a body of ground water in the sand. The capping till sheet is probably somewhat less permeable than the underlying sand, but it is so thin and so much broken through by innumerable natural and artificial cuts that it does not serve to any appreciable extent as a water-shedding roof over the sand. These conditions make it impracticable to reduce the ground water in the hill by special works intended to gather the surface runoff into sewers before it seeps down into the sand. In other words, the volume of ground water in the sand cannot be decreased by diversion at the source.

The gradational contact of sand and underlying clay along the flanks of the fill is marked by a line of springs and seeps; many of the springs flow even at the end of dry summer seasons. It appears, therefore, that downward percolation during rainy winters tends to build up a low flattish dome-shaped body of ground water under the hill, and that the late summer seepage is supplied by a gradual flattening of this dome as the water moves slowly out through the sand just above the clay. There is in this sense a ground-water storage reservoir in the pore spaces in the sand under the hill; there are certainly no open caverns or "underground lakes."

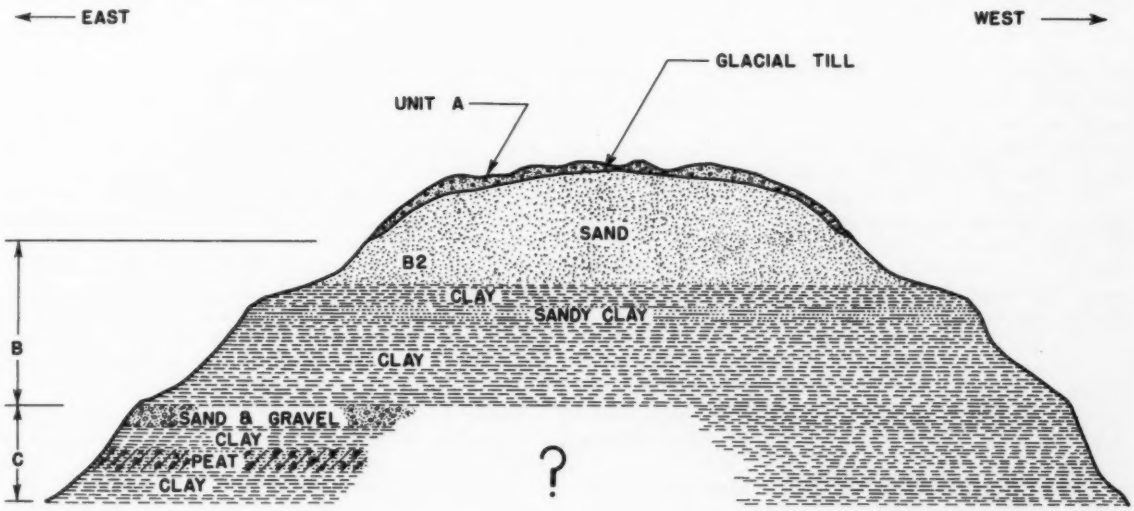
Bearing of the Geologic Relations on the Alki Avenue Slide Problem

The essential features of the Alki Avenue slide area are (1) a steep slope at the base of the bluff due to wave cutting in the clay, (2) a hummocky terrace at the level of the clay-sand contact zone, and (3) another steep slope ascending from the terrace to the flattish top of the hill. The slides originate as slumps of sand and overlying till from the upper cliff onto the terrace; typical backward tilting of large and small slumped blocks indicate that the movement occurs on curved sliding planes that extend downward to the zone of seepage at the terrace level. The clay that makes up the lower cliff is not involved in the landslide movement—the blocks that slump off the upper cliff disintegrate into a jumbled mass of water-saturated debris that moves across

the terrace as a "mudflow" and spills over the lip of the lower cliff into the backyards of the Alki Point residences. The same process (change from slumping of blocks in the upper part of a slide area into a mudflow type of movement below) is seen northwest of the Marine Hospital, except that there the mudflow mass advances down across a gentle slope instead of pouring over a cliff.

The geologic background causes for the sliding are (1) former oversteepening of the bluff as a whole by wave cutting at the base, and (2), emergence of ground water at the sand-clay contact zone. It is important in this connection to note that the terrace of the slide area is a continuous feature along the bluff from Duwamish Head to Alki Point and beyond. This terrace is everywhere due to the process seen in operation in the slide area, namely, slumping of the sandy portion of the bluff above the seep zone at the top of the clay. Because development of the terrace predates occupation of the area by white men, landsliding is evidently the natural or normal manner of retreat of the bluff. The slide area is simply a segment of the bluff where the process is now active; the remainder of the terrace carries houses and trees indicating relative stability within the last 50 to 100 years. It may be noted during the progress of this report that there is not *necessarily* any specific reason for localization of the sliding that is now causing trouble. Cliffs that retreat by landsliding usually do not break away everywhere along their length at the same time, but characteristically show local areas of active sliding that shift in position from place to place and from time to time.

It seems evident, in view of the geologic relations, that artificial terracing, construction of retaining walls, or other superficial control measures would be completely useless, and that the slide area can be stabilized only by drainage of the sand-clay contact zone. The term "zone" is used because the lip of the lower cliff is certainly not the top of the clay; clay layers interbedded with sand are exposed above the lip in the slide area and at still higher levels in the relatively stable portion of the terrace just to the north. Exploratory drilling will therefore be needed to determine whether the principal flow of water is at the top of the uppermost clay layer concealed in the slide debris high on the terrace, or whether the water moves out chiefly through a sand layer interbedded near the top of the clay lower down on the terrace. Vertical holes entering a short distance back from the top of the bluff, or inclined holes entering at the base of the cliff, should answer this question; in addition, pumping tests, etc. on these holes will supply data as to permeability that will be much needed by the engineer who designs the drainage system. If, for example, the water-bearing sand proves to be highly permeable, it is possible that intermittent pumping from a small number of wells situated a few hundred feet back from the top of the bluff may, by an overlapping of cones of depression, lower the water table sufficiently to give a large measure of relief at a relatively low cost.



DIAGRAMMATIC CROSS SECTION OF WEST SEATTLE

LOOKING SOUTH

The water that would be intercepted by a drainage system does little damage until it emerges from the sand into the landslide debris at the base of the upper cliff. Or, to put it another way, it is the flowage of the water-saturated material down across the terrace that permits continued slumping of the upper cliff. It may be significant, therefore, (1) that the terrace in the area of active sliding is largely stripped of trees, while the relatively stable part of the terrace to the north and south is heavily overgrown by large trees, and (2) that trees of the type that have been cut from the terrace in the slide area transpire very large amounts of water per day. This has long been known in general—recent reports in engineering and scientific journals, based on experimental studies, emphasize the important role played by tree roots as dewatering agents. Stumps of trees several feet across in the slide area indicate relative stability in that area when the trees were growing. This fact, plus the localization of sliding in the cleared area, and notably greater seepage at the surface in the cleared area than in the timbered portion of the terrace to the north and south, suggests that the cutting of the trees may have played a part in localizing the sliding, or may aggravate the bad condition if the beginning of the sliding was due to other causes.

This should not be construed to mean that the writer thinks that the tree cutting is wholly, or even in a large measure, responsible for the sliding. The relationships simply indicate that it would be well to discourage further tree cutting, and to do everything possible to promote the growth of trees on the landslide terrace as an inexpensive means of drawing water from the debris that mantles the terrace.

Rubbish and earth are now being dumped over the edge of the upper cliff at one point on a considerable scale. This material simply flows down across the terrace surface and ends up in the backyards of the houses along Alki Avenue. It is very doubtful whether the dumped material is at all effective in decreasing the rate of slumping of the upper cliff, and, for the benefit of all concerned, the practice probably should be discouraged.

Possible Future Utilization of Ground Water in the Seattle Area

Consideration of pumping from wells as a means of getting rid of water as a landslide control measure leads to the thought that ground water may at some future time be utilized to supplement our present supply from the Cascades. The very rapid growth of Seattle, and the experience of Tacoma as regards costs, etc., give point to the suggestion. One of the by-products of the present investigation, available when and if needed, will be a large amount of subsurface data on which a well-drilling program can be based.

NACA Signs Contract for Aeronautical Research

A $10,000 contract for research on rolling characteristics of swept-back wings on jet-propelled aircraft was awarded the Aeronautical Engineering Department of the University of Washington last June by the National Advisory Committee for Aeronautics.

The specific purpose of the tests is "to determine, experimentally, the loss in rolling performance due to bending and torsional deflections of elastic wing models; to compare the rolling performance of non-swept and swept-back wings with each other and with theory; and to determine the effect of control surface size on the loss in rolling performance." Tests will be run in the university wind tunnel on models of about 4-ft span free to rotate about an axis parallel to the direction of motion and designed to have bending and torsional stiffness characteristics similar to those of full scale aircraft.

The loss in rolling performance of airplanes that is due to torsional deflection has always been serious, but with the introduction of sweepback, as on the Boeing XB-47, both torsion and bending of the wing affect the rate of roll of the airplane. That is, as speeds are increased the aerodynamic forces and moments caused by operations of ailerons result in the case of a swept wing in large bending and twisting deformations of the wing which tend to oppose the lateral control forces, while in a straight wing only twisting deformations affect lateral control.

V. M. Ganzer, Assistant Professor of Aeronautical Engineering, who will supervise the project, became familiar with the problem while working at the Boeing Airplane Company on the XB-47 and did some work on it. Since then several theoretical approaches to the problem have been made, and the NACA has become sufficiently interested to authorize this experimental investigation. This work is very important in the design of any high-speed swept-back wing airplane and should have wide application since results of the experiments will provide data for checking the accuracy of existing theory.

Henry A. Cole, Jr., a graduate student in aeronautical engineering, will be in charge of design of equipment and models, and evaluation of data. He is a former Research Fellow in the Engineering Experiment Station and until recently was working, under the supervision of Professor Ganzer, on Project No. 53 which involves a study similar to that covered in the contract.

Robert G. Joppa, Research Associate in Aeronautical Engineering, will design instruments for the equipment and is in charge of directing the crew.

CERAMIC TESTS OF NORTHWEST CLAYS*

Kenneth G. Skinner

Chemical Engineer, Northwest Experiment Station

Hal J. Kelly

Metallurgical Engineer, Northwest Experiment Station

The industrial growth on the Pacific Coast, just prior to and during the war, caused a sudden increase in the demand for refractories and various ceramic products which was paralleled with requests for information regarding sources of raw materials. In an effort to supply part of this information, the Bureau of Mines in co-operation with the College of Mines, University of Washington, started a program in 1944 to test the refractory and other properties of clays from seven Pacific Northwest deposits. They were drilled as part of the Bureau of Mines alumina-from-clay investigation. All of the deposits except the Whiteware, Montana, deposit, are within 150 miles of either Seattle, Tacoma, or Spokane, Washington, or Portland, Oregon, and all are near rail transportation. The Whiteware deposit is about 600 miles east of Spokane.

*An abstract of a forthcoming Bureau of Mines Report of Investigation giving the result of work done under a co-operative agreement between the Northwest Experiment Station, Department of the Interior, Bureau of Mines, and the University of Washington.

Instead of testing every sample collected in the exploratory drilling campaign certain samples were selected on the basis of their available alumina (acid soluble after calcination at 700° C.) and available iron content, and on the basis of the drill hole location. These interval samples were tested for refractoriness as indicated by P.C.E. tests, plasticity, and fired colors at cones 04 (about 1055° C.) and 4 (about 1175° C.).

All the ceramic and chemical data were tabulated and from these results diagrams were drawn for the holes, showing the footage for each sample and the refractoriness and fired colors at cones 04 and 4. As further visual aids, and also to help in estimating mining conditions and tonnages, idealized vertical sections were drawn showing the refractory classification of the clays in the different deposits. Fig. 1 is an example. The vertical scale is exaggerated 5:1 in order to show the smaller bands of clay.

On the basis of present data, the Whiteware, Montana, clay could be used to manufacture super-duty firebrick; the Cowlitz, Washington, the Hobart

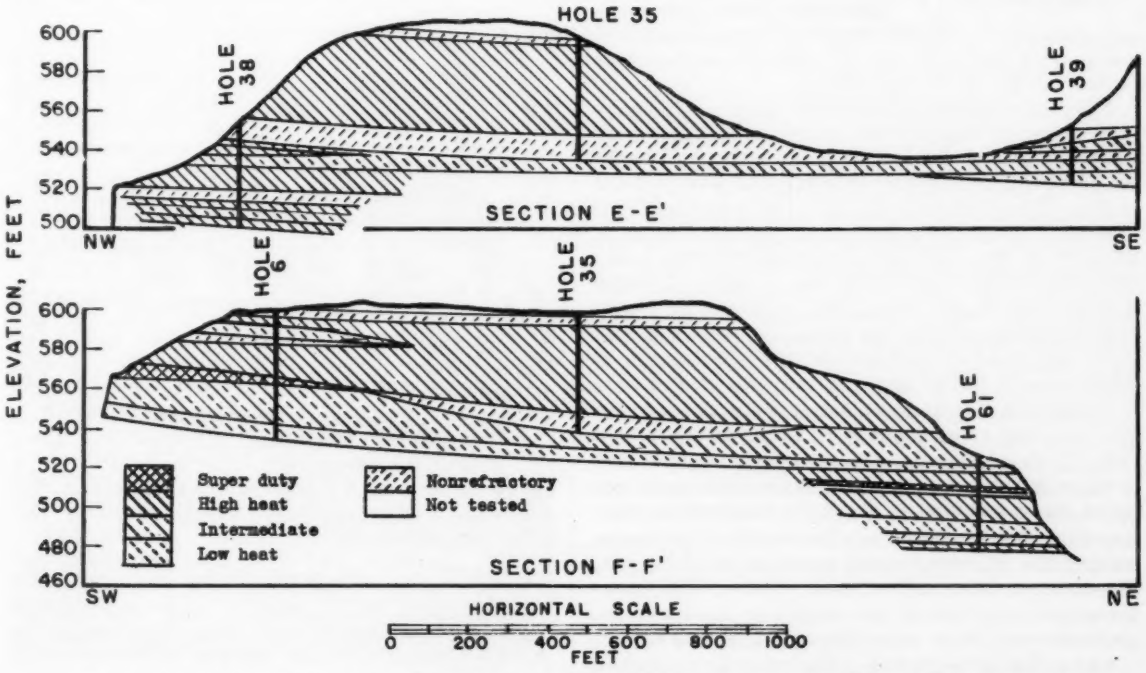


Fig. 1. Idealized Sections Showing Refractory Classification of Samples from Cowlitz Deposit

Butte, Oregon, and the Olson, Idaho, clay could be used for high heat duty brick; the Excelsior, Washington, for intermediate heat duty; Molalla, Oregon, for low and possible intermediate heat duty brick; but the Five Mile Prairie, Washington, material would probably have little value as a ceramic raw material. In some cases selective mining would have to be used because the satisfactory and unsatisfactory clays appear to be intercalated.

Further testing should be done before final evaluation is made of the deposits for their ceramic and refractory possibilities. Workability, and drying and firing characteristics are some of the factors that should be determined. Test holes drilled on closer centers and samples representing smaller intervals would be desirable.

CORROSION STUDIES ON 24ST ALUMINUM

William Maske

Research Chemist in the Engineering Experiment Station

William Maske

Of considerable economic importance to Seattle and adjacent areas is the protection of piling from marine borers. In Florida, where piles have been jacketed with sheet aluminum with the intervening spaces grouted with a mortar, little deterioration of the jacket took place over a period of six years. A study in accelerating natural corrosion in the laboratory was accordingly undertaken at the Engineering Experiment Station to determine if the useful life of aluminum and its alloys in salt water could be predicted.

The present report is limited to some preliminary data obtained using 24 ST, one of the alloys most severely attacked by sea water. Instead of Puget Sound water, a standard solution (2.5 per cent CP sodium chloride) was used as a norm because it is reproducible and different variables can easily be added to it. Since corrosion took place in this solution much faster than in the two samples of Puget Sound water tested, it was also used as one means of accelerating natural sea water deterioration. Results have been correlated with the two samples of Puget Sound water brought into the laboratory.

A variable temperature bath previously used for Warburg tests was adapted to serve as equipment (Fig. 1). Corroding solutions are held in glass jars of which the tops can be seen. Suspension hooks are pyrex glass, mounted as shown for intermittent submersion, and hooked on the jar rim for continuous submersion, thereby avoiding metal-to-metal contact. The inverted Erlenmeyer flasks, used for replenishing evaporation losses, are needed at elevated temperature only. Cycle and stroke length, can be varied.

The following method was developed as a standard procedure for determining corrosion by weight loss.

1. All glassware, previously cleaned, was given a rinse with 1 to 1 hydrochloric acid and then rinsed under running water.
2. Sample bars 1/2 in. by 4-7/16 in. were cut from 12-gauge stock previously abraded with 180-grit aloxite cloth, and a 1/4-inch hole was drilled midway in one end, with all edges smooth.
3. All samples were precleaned by two abrasion operations to remove grease and tarnish by light scrubbing with a soft brush, using equal parts of pumicite and Fuller's earth followed by brushing under running water. If uniform

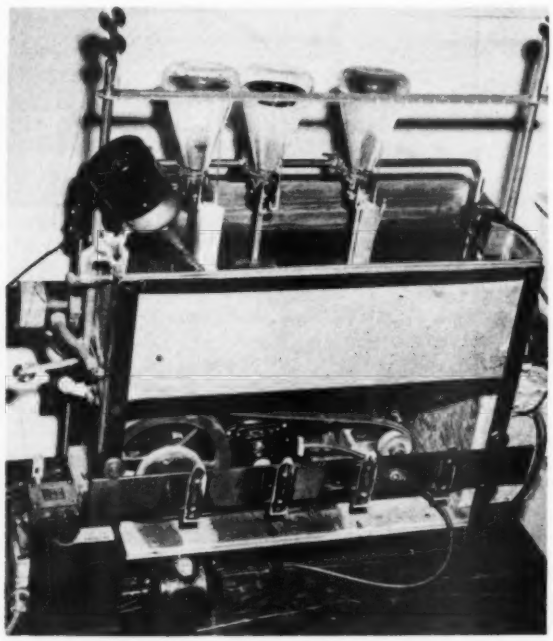


Fig. 1. Accelerated Corrosion Machine

wetting did not result, the operation was repeated. Samples were thoroughly dried and weighed.

4. Jars were filled with 1200 ml. of solution.
5. Samples were preconditioned by running them under actual operating conditions for about two days. Four samples were made each test, two for continuous, and two for intermittent submersion. The standard cycle was 6 minutes, the stroke length, 6-1/2 in. and the temperature, 25°C.
6. The samples were rinsed, blotted and oven-dried. Corroded aluminum was removed by pickling in concentrated CP nitric acid for five minutes, then scrubbing lightly under running water with a soft bristle brush, followed by blotting and oven drying. For good reproducibility it was found advisable to repeat pickling, cleaning, and drying. Care was taken that samples were thoroughly dried before being dipped in acid. Acid was reused, and the temperature of the room controlled acid temperature.
7. The dry bars, when cool, were placed in a dessicator and weighed in grams to 4 places.
8. The corrosion run of 48± 1 hours was made.
9. Steps 5, 6, 7 were repeated.

The difference in the two weights gave the total corrosion loss, and this result divided by 10 gave the loss in g. per sq. in. per day.

In the corrosive action of sodium chloride on 24ST, hydrogen is given off and some of the copper and chromium in the alloy taken off by corrosion immediately plates on the metal and is oxidized through electrolysis. In acid and neutral solutions this plating, though not severe, is enough to give a grayish color to the metal. In alkaline solutions where it is heavy enough to be significant, it is grayish black or black in color and offers considerable protection against further weight loss (Table 1, Samples 3 and 6), except for pitting, of which more will be said later. This coating is not readily attacked by concentrated nitric acid and hence remains during the test as outlined. Since this protective coat forms under natural corrosion in alkaline media, it probably should not be removed for analytical purposes. However, caution must be used or the coating will be removed if it is hand scrubbed too vigorously or with too stiff a brush.

The first objective in applying the foregoing procedure to the accelerated corrosion study was to determine how much faster 24ST corroded in 2-1/2 per cent NaCl brine than in a sample of Puget Sound water. Table I shows the results.

While *continuous* immersion in brine shows moderate accelerated corrosion compared to that in Puget Sound water, *intermittent* immersion shows marked acceleration.

The Duwamish River at the point the water sample was taken contains a substantial amount of raw sewage. Attempts to evaluate the amount of sewage in this water have been unsuccessful, no correlation being formed as yet between biochemical oxygen demand, permanganate demand, and volatile solids.

TABLE I

WEIGHT LOSS OF 12-GAUGE 24ST DURING STANDARD PROCEDURE
(g./sq. in. /day)

Type of Submersion	Sample No.	Stale Puget Sound	2-1/2% NaCl	2-1/2% NaCl Sewage Added
Intermittent	1	0.000077	0.0023	0.000047
	2	0.000093	0.0022	0.000053
	3		0.0020	
	4		0.0021	
	5		0.0026	
Continuous	1	0.000057	0.00020	0.000027
	2	0.000067	0.00024	0.000028
	3		0.00023	
	4		0.00023	
	5		0.00030	
	6		0.00050	

Temperature: 25°C
Sewage: fresh Sand Point Naval Air Station influent.
Puget Sound water: from surface, Duwamish River at Fisher Flouring Mills Co. dock, sample about three months old.

Corrosion Acceleration: Stale Puget Sound water 23/62 = 37%
2-1/2% NaCl . . . . 196/24 = 820%

TABLE II

WEIGHT LOSS OF 12-GAUGE 24ST AFTER 2 DAYS CONTINUOUS IMMERSION
(1/2-in. by 5-in. samples in 25-ml test tubes)

Variables	Fresh Puget Sound Water		2-1/2% NaCl		Stale 2-1/2% NaCl + Sewage		Fresh 2-1/2% NaCl + Sewage	
	pH	Weight Loss (g)	pH	Weight Loss (g)	pH	Weight Loss (g)	pH	Weight Loss (g)
None	7.92	0.0018	7.02	0.0020	8.11	0.0021	7.71	0.0013
N/10 Acidity	4.26	0.0019	4.28	0.0074	3.63	0.0023	2.68	0.0013
N/10 Alkalinity	9.31	0.0025	9.98	0.0063	9.39	0.0018	9.62	0.0049
Neutral +10 ppm Fe	7.99	0.0018	5.90	0.0024	8.17	0.0021	7.77	0.0016
N/10 Acidity + 10 ppm Fe	4.23	0.0019	4.32	0.0077	4.01	0.0027	3.19	0.0017
N/10 Alkalinity + 10 ppm Fe	9.56	0.0026	9.85	0.0132	9.42	0.0021	9.65	0.0055

Temperature: 27°C.

To try to determine the effect of sewage in the Sound water sample raw sewage was added to brine, and the results shown in Table I indicate sewage may be an important inhibitor present in the water sample.

During the short period of time covered by these tests, little could be determined concerning the type of corrosion taking place, nor can any explanation be given at this time for the considerable differences existing between results under apparently identical test conditions.

Tests were run to determine if corrosion could be accelerated by increasing salt concentration. In a 15 per cent solution less corrosion took place than in a 2.5 per cent solution, two runs at 15 per cent showing average losses of 0.00018 and 0.00012 g. per sq. in. per day by intermittent and continuous submersion, respectively.

The next step in attempting to obtain faster corrosion consisted of varying pH, temperature, and Fe content. Table II indicates the results, which cannot be compared directly with those in Table I, because of a change in the standard procedure which altered the ratio between sample area and amount of solution. In Table II, 1/2-in. by 5-in. carefully machined samples and 25-ml. test tubes filled with solution were used. The data in Table II indicate that, by changing pH, corrosion of 24ST can be accelerated as much as three times in 2-1/2 per cent salt brine.

The correlation between the weight loss in stale brine with sewage added compared to Puget Sound water is reasonably close, and a repeat run made with this type of sewage adjusted to the pH of Puget Sound water confirms these findings. This relationship was not expected since it had been believed that Puget Sound water, because of dilution, would offer less corrosive protection than salt sewage. Apparently salt sewage can withstand considerable dilution before its protective properties are diminished.

Iron is known to be corrosive to aluminum. Freshly precipitated and washed ferric hydroxide was added to the solutions shown in Table II. Results were significant only in alkaline solutions in concentrations of 10 p.p.m., and, with salt brine, corrosion increased about two times. Puget Sound water either was not sufficiently alkaline, or was too well protected to indicate much change. These findings support the accepted theory that with iron present both Fe-Al and Cu-Al cells could exist, with voltages of 2.35 and 2.74 volts, respectively, and hence, unless iron concentration is high, the electrolytic effects of copper overbalance those of iron.

In the few tests which have been made at higher temperatures, little acceleration took place up to 45°C. However, at 65°C nearly three times the corrosion took place as that found at 25°C in salt brine, and four immersions in nitric acid and considerable scrubbing were necessary to remove corrosion products.

Little can be reported about pitting from the work done, other than that, in both neutral and alkaline solutions, it is more severe under intermittent than under continuous submersion. No mathematical evaluation was attempted.

Results

In the laboratory, corrosion of 24ST aluminum in a sample of Puget Sound water was increased 47 per cent by intermittent immersion over that produced by continuous immersion, and 39 per cent by changing the pH of the water.

Corrosion of 24ST in salt brine in the laboratory was increased 820 per cent by intermittent immersion over that produced by continuous immersion. During continuous immersion in salt brine, corrosion was increased up to 300 per cent by changing pH,

(Continued on page 32)

Notes and Comments

DISTINGUISHED RESEARCH FELLOW

T. C. Lin

The Engineering Experiment Station is fortunate in having among its research fellows Dr. Tung Chi Lin. Dr. Lin who was born in Peking, China, received his B.S. in Aeronautical Engineering from National Central University, Chunking, China in 1942. During the war he was assigned to the No. 2 Aeroplane Manufacturing Works of the Chinese Commission of Aeronautical Affairs, Nanchwan, Szechwan, China, in engine repair and test, and airframe assembly and flight test. In late 1945 he was awarded a post-graduate apprenticeship in the Bristol Aeroplane Co., Ltd., Bristol, England, and in 1946 entered Queen Mary College, University of London, where in 1948 he received his Ph.D. in Aeronautical Engineering.

His research work at the University of London, conducted under N. A. V. Piercy, Head of the Department of Aeronautics of Queen Mary College, dealt with the elastic properties of hyperbolic (Piercy) airfoils with particular reference to their use in compressors, turbines, and airscrews. Since coming to the University of Washington, Dr. Lin has continued his interest in Piercy airfoils and has worked with other graduate aeronautical students on structural problems involved in the design of these airfoils. His present research work is on boundary layer phenomena, and particularly slip-flow coefficients, and is preliminary to future testing in the supersonic wind tunnel now being completed by the Aeronautical Engineering Department.

Dr. Lin's brother, T. Y. Lin, is an assistant professor of civil engineering at the University of California.

ENGINEERS IN THE NEWS

ALBERT L. PURVIS, who held a research fellowship in the Engineering Experiment Station during 1948 and received his M.S. in Ch.E. at the end of that year, was appointed in January to the staff of the University of British Columbia to teach senior courses in chemical engineering.

PETER D. JOHNSON, Assistant Professor of Mineral Engineering, attended the convention of the American Ceramic Society at Cincinnati April 24 to 28, where he presented two papers before the Refractories Division: "Induction Furnace for High Temperature Ceramic Research," and "Refractory Reactions in Vacuum." He also read the latter paper before the AIME meeting in Spokane on May 14.

B. L. GRONDAL, Professor of Forest Products, presented a paper on field inspection of utility poles at the meeting of the American Wood Preservers Association held in St. Louis, April 26 to 28.

At the same meeting, O. H. SCHRADER, JR., Associate Professor of Forest Products, presented the report of the committee on treating standards for Douglas fir, western hemlock, intermountain Douglas fir, and western larch. The report included a research study on the penetration of creosote oil in round Douglas fir poles and piles. Professor Schrader has been appointed Technical Director of the Institute of Forest Products of the state of Washington and will hereafter divide his time between the duties of that office and his teaching.

VERNON L. McCLOSKEY, M.E. student of the University of Washington, was awarded first prize for a paper, "The Rotary Engine," at the annual Pacific Northwest Student Conference of the ASME held on the campus in May. His work was chosen the best of eight papers presented during the conference by students from the University of British Columbia, University of Idaho, Washington State College, and University of Washington. As first prize winner, McCloskey attended the semi-annual meeting of the professional branch of the ASME held in June in San Francisco. CARLOS de GRIEF, another University representative, won fifth prize for "Cam Engine."

A committee to gather information on the earthquake of April 13 and map out a program of research includes A. L. MILLER, Professor of Civil Engineering, and C. E. WEAVER and G. E. GOODSPEED, Professors of Geology. Reports are being contributed by technical societies, industrial organizations, and individuals.

IRVING LARSON, co-author of the article, "Electroforming Iron," is now with the Research Department, Electrochemical Division, of the E. I. Dupont de Nemours Company at Niagara Falls, New York.

B. T. McMINN, Professor of Mechanical Engineering, and R. B. VAN HORN, Professor of Civil Engineering, took part in the "Symposium on Work Load Evaluation of Engineering Faculty" at the meeting

of the Pacific Northwest Section of the ASEE at Bozeman, June 17.

H. E. WESSMAN, Dean of the College of Engineering, and six of his faculty members attended the meetings of the ASEE held June 20 to 24 at Rensselaer Polytechnic Institute, Troy, New York. Dean Wessman discussed "Standards and Facilities for Graduate Instruction in Engineering," on the panel for "Requirements for the Doctor's Degree." He also presented the George Westinghouse Award of 1949 for the outstanding engineering teacher in the United States to Joseph Marin, Professor of Engineering Mechanics, Pennsylvania State College.

F. B. FARQUHARSON, Director of the Experiment Station, on his way east to attend the Troy meeting stopped at Bozeman, Montana, where he presented a paper on "A Co-ordinated Program for Engineering Graduate Research in the Northwest" before the Pacific Northwest Conference on Engineering Education. Later, in New York, he met with the Advisory Board on the Investigation of Suspension Bridges.

The 1950 meeting of the ASEE will be held in Seattle, with the University of Washington as host. Approximately 1500 members are expected to attend.

A meeting of representatives of six northwest colleges and universities will be held in Spokane in November to study ways and means of integrating research in the Northwest through branches of the Engineering College Research Council. Directors of engineering experiment stations, or their equivalent, expected to attend will include **F. B. FARQUHARSON**, of the University of Washington, who is in charge of the meeting, **E. W. SCHILLING**, Montana State College, Bozeman, **J. P. SPIELMAN**, Montana School of Mines, Butte, **A. S. JANSSEN**, University of Idaho, Moscow, **S. H. GRAF**, Oregon State College, Corvallis, and **H. J. DANA**, Washington State College, Pullman.

CORROSION STUDIES ON 24ST ALUMINUM

(Continued from page 30)

another 200 per cent by adding 10 p.p.m. of iron. In another continuous immersion test, corrosion was increased 300 per cent by increasing the temperature from 25°C to 65°C.

No correlation has been established between laboratory accelerated corrosion of 24ST in salt brine and extended corrosion in Puget Sound water.

Little progress, moreover, has been made so far in these studies towards developing an accelerated corrosion test in Puget Sound water even for 24ST which was chosen for this preliminary work because of its rapid corrosion rate. The project, if extended to cover alloys such as 2S, 3S, or 52S, which would normally be considered for this application, might reveal useful data.

RECENT PUBLICATIONS

Bulletin No. 115. The Influence of Random Roughness on Flow in Pipes, Charles W. Harris, 19 pp., 1949

Bulletin No. 116. Part I. Aerodynamic Stability of Suspension Bridges. Part I: Investigations Prior to October, 1941, F. B. Farquharson, 103 pp., 1949

Bulletin No. 116. Part II. Aerodynamic Stability of Suspension Bridges. Part II: Mathematical Analyses, Frederick C. Smith and George S. Vincent. (In press.)

Bulletin No. 116. Part III. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part III: The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind, F. B. Farquharson. (In preparation.)

Bulletin No. 117. Production of Wood Coke from Waste Wood, Warren L. Beuschlein. (In press.)

Reprint No. 21. "Biochemical Oxygen Demand of Sulfite Waste Liquor," Richard G. Tyler, Shirley Gunter, *Sewage Works Journal*, July, 1948

Reprint No. 22. "Physical Properties of Iron Deposited from Chloride Baths," I. Larson, R. W. Moulton, G. L. Putnam, *Journal of the Electrochemical Society*, Vol. 95, No. 4 (April, 1949)

NEW RESEARCH PROJECTS

Project 65. Library Research for Mechanical Engineering. E. E. Day, Assistant Professor of Mechanical Engineering, Supervisor; Tsu Tao Loo, Research Fellow.

Project 66. Engineering Geology of the Seattle Area. J. Hoover Mackin, Professor of Geology, Supervisor; D. R. Mullineaux and W. J. Stark, Research Fellows.

Project 67. Earthquake Investigation. C. E. Weaver, Professor of Geology and A. L. Miller, Professor of Civil Engineering; Supervisors.

Project 68. A Study of Design Requirements for Loud-Speaker Enclosures. R. L. Tanner, Instructor in Electrical Engineering, Supervisor; J. H. Whiting, Research Fellow.

Project 69. A Study of the Factors Affecting the Adsorptive Capacity of Activated Charcoal. R. W. Moulton, Associate Professor of Chemical Engineering, Supervisor, N. R. Mukherjee, Postdoctorate Research Fellow.

Project 70. Gas Turbine Combustion Circuits. Michael Guidon, Instructor in Mechanical Engineering, Supervisor; O. A. Foss, Research Fellow.

Project 71. Study of Wastes of State Industrial Plants to Determine Their Characteristics and Concentration. R. G. Tyler, Professor of Civil Engineering, Supervisor; F. W. Williams, Research Fellow.

PUBLICATIONS
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Requests for copies of publications should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.
All publications are free on request.

BULLETINS

48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris. 35 pp. 1928.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred Scoville Eastman. 20 pp. 1931.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Harris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
60. An Electromagnetic Balance for Force Measurement of Current Control. Fred Scoville Eastman. 29 pp. 1932.
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74. The Deformation of Hard Grade Reinforcing Steel During and After Construction in a Reinforced Concrete Building. Sergius Ivan Sergev. 33 pp. 1933.
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108. Silica Sands of Washington. Hewitt Wilson, Kenneth G. Skinner and Albert H. Couch. 76 pp. 1942.
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116. Part III. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part III, The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. (In preparation.)

REPORTS

2. Iron and Steel Manufacture in Washington, Oregon, California and Utah. Joseph Daniels. 69 pp. 1929.
3. Coal in Washington. Joseph Daniels. 17 pp. 1934.
4. Water Resources of Washington. Richard Gaines Tyler. 61 pp. 1938.
5. The Terminal Plan: An Improved System of Urban Transportation. Austin Vitruvius Eastman. 64 pp. 1938.

TECHNICAL NOTES

2. The Modulus of Elasticity of the High Strength Concrete Used in the Ross Dam. F. C. Smith. 16 pp. 1940.
3. The Theory of Fractional Parts Developed for Structural Beam-column Members Preceded by an Elementary Discussion of Simple Beam and Column Design. Sybren Ruurd Tymstra. 32 pp. 1943.
4. Gaging Chart for Horizontal Cylindrical Tanks with Flat Heads or with Convex Heads. Sybren Ruurd Tymstra. 4 pp. 1944.
5. Gaging Chart for Cylindrical Tanks with Different Types of Heads. Sybren Ruurd Tymstra. 7 pp. 1945.
6. The Heat Pump for Residential Heating. G. S. Smith, H. Christensen, and A. Presson. 23 pp. 1948.

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